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FEASIBILITY STUDY FOR AIR FORCE PLANT 4 VOLUME 1 OF 2 NAS FORT WORTH TX
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**NAVAL AIR STATION
FORT WORTH JRB
CARSWELL FIELD
TEXAS**

**ADMINISTRATIVE RECORD
COVER SHEET**

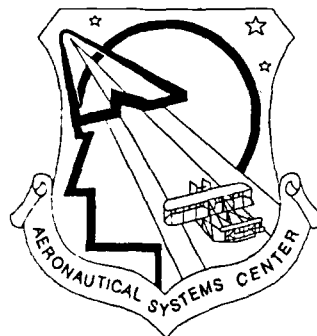
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Air Force Plant 4

Feasibility Study

September 1995

Prepared for
U.S. Department of the Air Force
Headquarters Aeronautical Systems Center
Wright-Patterson Air Force Base, Ohio



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**Under DOE Contract No. DE-AC04-86ID12584 with the
U. S. Department of Energy
Grand Junction Projects Office
Grand Junction, Colorado**

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List of Acronyms

ARAR	Applicable or Relevant and Appropriate Requirements
ASC	Aeronautical Systems Center
atm	atmospheres
BAP	benzo(a)pyrene
BDAT	Best Demonstrated Available Technology
BNA	base neutral acid
BOD	biochemical oxygen demand
BRA	Baseline Risk Assessment
BTEX	benzene, toluene, ethylbenzene, and xylene
CAFB	Carswell Air Force Base
Cd	cadmium
CERCLA	Comprehensive Environmental, Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
cm/sec	centimeters per second
CO	carbon monoxide
COCs	chemicals of concern
COD	chemical oxygen demand
Cr	chromium
C ₂ O ₃	solubility of chromate
CRDL	Contract Required Detection Limit
CRQL	Contract Required Quantitation Limit
CWA	Clean Water Act
CWM	Chemical Waste Management
cy	cubic yard
DCA	dichloroethane
DCE	dichloroethene
DCP	dichloropropane
DDD	p,p'-dichlorodiphenyldichloroethane
DDE	p,p'-dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DNAPL	dense nonaqueous phase liquid
DOE	U.S. Department of Energy
DOE-GJPO	U.S. Department of Energy Grand Junction Projects Office
DOT	U.S. Department of Transportation
DYCP	Die Yard Chemical Pits
EPA	Environmental Protection Agency
FDTA	Fire Department Training Area
FEMA	Federal Emergency Management Agency
FFSA	Former Fuel Storage Area
f _{oc}	fraction organic carbon
Freon 12	dichlorodifluoromethane
FS	Feasibility Study
FSA	Fuel Saturation Area
FTA	Fuel Test Area

List of Acronyms (continued)

gc/ms	gas chromatography/mass spectrometry
GD	General Dynamics
Geotech	Rust Geotech
gpd	gallons per day
H	Henry's Law constant
H ₂ O ₂	hydrogen peroxide
HI	hazard index
I.D.	inside diameter
IDL	instrument detection limit
ILCR	incremental lifetime cancer risks
IRP	Installation Restoration Program
ISV	in-situ verification
JETS	Jet Engine Test Stand
K _d	distribution coefficient
K _{oc}	organic carbon/water partition coefficient
K _{ow}	octanol/water partition coefficient
LDR	land disposal restrictions
LNAPLs	light nonaqueous phase liquids
logK _{oc}	logarithm of K _{oc}
logK _{ow}	logarithm of K _{ow}
MCL	maximum contaminant level
mg/cm ³	milligrams per cubic centimeters
mgd	million gallons per day
mm	millimeter
mol/L	moles per liter
mol/m ³	moles per cubic meter
MSCL	Mississippi State Chemical Laboratory
NAPL	nonaqueous phase liquid
NARF	Nuclear Aerospace Research Facility
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NO ₂	nitrogen dioxide
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O ₃	ozone
O.D.	outside diameter
O&M	operating and maintenance
OSHA	Occupational Safety and Health Administration
PA/SI	Preliminary Assessment/Site Inspection
PAHs	polynuclear aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene
pCi/g	pico Curies per gram
PID	photoionization detector
PMIO	total particulates

List of Acronyms (continued)

POTW	Publicly Owned Treatment Works
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
PPMTL	priority-pollutant metals
PRGs	preliminary remediation goals
RAOs	remedial action objectives
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation Report
RI/FS	Remedial Investigation/Feasibility Study
RME	reasonable maximum exposure
ROD	Record of Decision
RSD	relative standard deviation
SAP	Sampling and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SMCL	secondary maximum contaminant level
SO ₂	sulfur dioxide
St.	storm drain
sy	square yard
TAC	Texas Administration Code
TAL	Target Analyte List
TCA	trichloroethane
TCE	trichloroethene
TCL	Target Compound List
TCLP	toxicity characteristic leaching procedure
TH	Test Holes
TNRCC	Texas Natural Resource Conservation Commission
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TSCA	Toxic Substances Control Act
USAF	United States Air Force
USFWS	United States Fish and Wildlife Service
UST	underground storage tank
UV	ultraviolet
VOA	volatile organic acid
VOCs	volatile organic compounds
WWCB	Waste Water Collection Basin
°F	degrees Fahrenheit
µg/g	micrograms per gram
µg/m ³	micrograms per cubic meter
µg/kg	micrograms per kilogram
µg/L	micrograms per liter

Executive Summary

This Feasibility Study presents the remedial alternatives developed to address contamination on Air Force Plant 4. Remedial alternatives were developed in response to contamination that exceeded risk threshold values, as calculated by the baseline risk assessment (BRA). The BRA is presented in Section 6.0 of the Remedial Investigation Report.

Areas of Contamination

Groundwater contamination exceeded risk threshold values in two areas – the Paluxy aquifer and the East Parking Lot Plume in the Upper Zone aquifer. Soil/sediment contamination exceeded risk threshold values at four areas – Landfill No. 4, Landfill No. 3, Meandering Road Creek (this includes the inlet to Lake Worth), and Building 181. Landfill No. 4, Landfill No. 3, and Meandering Road Creek were grouped together for development of remedial alternatives.

The results of the BRA did not indicate significant human health or ecological impacts posed by contaminants in the surface water. The human health risks due to air contamination can not be directly attributed to past Plant 4 practices. Therefore, remedial action alternatives were not developed for air and surface water contamination.

Remedial Action Objectives

Remedial action objectives (RAOs) were developed for each area of contamination that exceeded risk threshold values. The RAOs incorporate the contaminants of concern, a quantitative cleanup level, and an exposure pathway. The primary contaminants of concern in the Paluxy aquifer are trichloroethene (TCE) and dichloroethene (DCE). The RAO for the Paluxy aquifer is to prevent human exposure from ingestion, inhalation during showering, and dermal exposure from showering to TCE concentrations exceeding 3.0 micrograms per liter ($\mu\text{g/L}$) and to DCE concentrations exceeding 70 $\mu\text{g/L}$ for *cis*-1,2-DCE and 100 $\mu\text{g/L}$ for *trans*-1,2-DCE.

Aqueous phase TCE and TCE dense nonaqueous phase liquid (DNAPL) are the primary contaminants of concern for the East Parking Lot Plume. The RAOs for the East Parking Lot Plume are to prevent TCE concentrations in the Window Area of the East Parking Lot Plume from exceeding 250 $\mu\text{g/L}$, to remove TCE DNAPL in the East Parking Lot Plume, and prevent groundwater with contamination above maximum contaminant levels (MCLs) from migrating off Plant 4 or Carswell Air Force Base (CAFB) boundaries. Removal of DNAPL will be demonstrated by dissolved TCE concentrations of less than 10,000 $\mu\text{g/L}$.

RAOs were developed separately for each of the four soil/sediment contamination areas. The contaminants of concern at Landfill No. 4 are benzo(a)pyrene (BAP), arsenic, cadmium, and copper. The RAOs for Landfill No. 4 are to prevent ingestion of BAP contaminated soils with concentrations exceeding the preliminary remediation goal (PRG) of 1.0 milligram per kilogram (mg/kg) and prevent the exposure of mice to arsenic, cadmium, and copper at levels which exceed 29.1 mg/kg, 132 mg/kg, and 563 mg/kg, respectively.

Copper, lead, and zinc are the contaminants of concern at Landfill No. 3. The RAO for Landfill No. 3 is to prevent exposure of mice to copper, lead, and zinc at levels which exceed 563 mg/kg, 2,000 mg/kg, and 1,000 mg/kg, respectively. Silver is the contaminant of concern in the sediments in Meandering Road Creek and Lake Worth. The RAO for Meandering Road Creek and Lake Worth is to prevent exposure of aquatic organisms to concentrations of silver above 1.0 mg/kg in the sediments. TCE in the vadose zone is the contaminant of concern at Building 181. The RAO for Building 181 is to prevent TCE concentrations in the soil exceeding 11.5 mg/kg, the level which could produce leachate above allowable levels in the Upper Zone groundwater.

Alternatives

Remedial action alternatives developed in a Feasibility Study are conceptual with respect to the level of engineering detail. The goal is to present enough information to establish the overall approach to select a preferred alternative for the Record of Decision. The details of the preferred alternative presented in the Record of Decision are developed during the remedial design phase.

Three alternatives were developed for the contamination in the Paluxy aquifer – No Action, Alternative 1; Alternate Water Supply, Alternative 2; and Pump and Treat with either Physical or Chemical Treatment, Alternative 3. The physical treatment method considered air stripping and the chemical treatment considered ultraviolet (UV) oxidation.

There were three alternatives developed for the East Parking Lot Plume – No Action, Alternative 1; Source Removal, Alternative 2; and Enhanced Source Removal with Physical Treatment, Alternative 3. Alternative 2 could use either physical or chemical treatment for the extracted groundwater. Alternative 3 only considers physical treatment of the extracted groundwater because it uses surfactants to enhance removal of DNAPL from the groundwater.

Landfill No. 4, Landfill No. 3, and Meandering Road Creek were grouped together for development of remedial alternatives. Five alternatives were developed for soil/sediment remediation at Landfill No. 4, Landfill No. 3, and Meandering Road Creek – No Action, Alternative 1; Capping that considers human health risk only, Alternative 2a; Capping that considers all risk areas, Alternative 2b; Removal/Disposal that considers human health risk only, Alternative 3a; and Removal/Disposal that considers all risk areas, Alternative 3b.

Two alternatives were developed for Building 181 – No Action, Alternative 1; and Soil Vapor Extraction (SVE), Alternative 2. The SVE Alternative was the only treatment alternative developed because SVE is considered a presumptive remedy by EPA that should be used whenever it is applicable at a site. Pilot tests have shown that SVE is effective at removing TCE from the vadose zone under Building 181.

The detailed analysis assessed each of the alternatives presented above against seven of the nine Comprehensive Environmental Response Compensation and Liability Act (CERCLA) evaluation criteria. The two criteria that were not included in the assessment are State acceptance and community acceptance. The assessment of these criteria will be included in the Record of Decision. Tables 4-1, 4-2, 4-3, and 4-4 present a comparison of the detailed analysis for each alternative.

Cost of Alternatives

Cost is one of the seven criteria used in the detailed analysis of alternatives. The present worth costs for an alternative are used to compare alternatives and are presented below. The reader will notice that a cost is given for some no action alternatives. The no action alternative cannot include any action to treat, contain, or stop exposure to contaminants but can include monitoring the contamination. The costs associated with the no action alternatives are monitoring costs. More detailed cost estimates for each alternative are presented in Section 4 with supporting information in Appendix B.

Paluxy Aquifer

Alternative 1 - No-Action	\$274,000
Alternative 2 - Alternative Water Supply	\$937,000
Alternative 3 - Pump and Treat w/ Physical Treatment	\$2,541,000
Alternative 3 - Pump and Treat w/ Chemical Treatment	\$3,101,000

East Parking Lot Plume

Alternative 1 - No Action	\$822,000
Alternative 2 - Source Removal w/ Physical Treatment	\$6,882,000
Alternative 2 - Source Removal w/ Chemical Treatment	\$7,334,000
Alternative 3 - Enhanced Source Removal w/ Physical Treatment	\$9,865,000

Soil at Landfill No. 4, Landfill No. 3, and Meandering Road Creek

Alternative 1 - No Action	\$73,000
Alternative 2a - Capping (human health risk only)	\$430,000
Alternative 2b - Capping (all risk areas)	\$472,000
Alternative 3a - Removal/Disposal (human health risk only)	\$19,151,000
Alternative 3b - Removal/Disposal (all risk areas)	\$19,244,000

Building 181

Alternative 1 - No Action	\$0
Alternative 2 - Soil Vapor Extraction	\$612,000

Air Force Plant 4 Sites

The remedial investigation characterized the nature and extent of contamination at several sites or areas with the potential to be affected by contamination from Air Force Plant 4. Most of the sites did have contamination but at levels that did not pose an unacceptable risk to human health or the environment, as determined by the BRA. No further response action will be done at these sites or areas. Some sites had contamination that exceeded risk threshold values and the FS developed remedial alternatives for these sites. Table ES-1 presents a summary of Air Force Plant 4 sites, findings of the BRA, and whether remedial alternatives were developed for the site or no further response action is planned.

Table ES-1 Summary of Air Force Plant 4 Sites/Areas of Concern

Site	Findings	Voluntary Actions/ Proposed Action
Media: Soil/Sediment		
Landfill No. 1 (Site LF01)	BAP exceeded the human health risk threshold value. However, the BAP is suspected to be from asphalt paving fragments and not from past waste disposal practices.	Completed voluntary action to remove contaminated soil. No further response action planned.
Landfill No. 2 (Site LF02)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Landfill No. 3 (Site LF03)	Copper, lead, and zinc exceed ecological risk thresholds. Contaminants do not pose an unacceptable risk to human health or the environment.	Remedial action alternatives developed in FS.
Landfill No. 4 (Site LF04)	BAP exceeds human health risk threshold, and arsenic, cadmium, and copper exceed ecological risk thresholds.	Remedial action alternatives developed in FS.
Fire Department Training Area (FDTA) No. 2 (Site FT05)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-3 (Site FT06)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-4 (Site FT07)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-5 (Site FT08)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-6 (Site FT09)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Chrome Pit No. 1 (Site DP10)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.

Table ES-1 (continued) Summary of Air Force Plant 4 Sites/Areas of Concern

Site	Findings	Voluntary Actions/ Proposed Action
Chrome Pit No. 2 (Site DP11)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Chrome Pit No. 3 (Site DP12)	Suspected TCE DNAPL area, although contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Die Yard Chemical Pits (Site DP13)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Fuel Saturation Area (FSA) No. 1 (Site SS14)	Fuel contamination at site, although contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove VOCs with soil vapor extraction. No further response action planned.
FSA-2 (Site SS15)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FSA-3 (Site SS16)	Fuel contamination at the site, although contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove VOCs with soil vapor extraction. No further response action planned.
Former Fuel Storage Area (Site SS17)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Solvent Lines (Site SS18)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Nuclear Aerospace Research Facility (Site OT19)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Waste Water Collection Basins (Site WP20)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
West Compass Rose (Site OT21)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.

Table ES-1 (continued) Summary of Air Force Plant 4 Sites/Areas of Concern

Site	Findings	Voluntary Actions/ Proposed Action
East Parking Lot/Flight Line (Site OT22)	Soil is not considered part of this site, only groundwater.	Not applicable, soil not included as part of this site.
French Drain (Site OT23)	French Drain is part of LF No. 1.	French Drain is a voluntary action at LF No. 1
Jet Engine Test Stand (Site OT24)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Underground Storage Tank (UST) No. 19 (Site ST25)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned.
UST No. 20 (Site ST26)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned.
UST No. 24A (Site ST27)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
UST No. 24B (Site ST28)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
UST No. 25A (Site ST29)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
UST No. 30 (Site ST30)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
Assembly Building/Parts Plant Perimeter (Building 181)	Contaminants do not pose an unacceptable risk to human health or the environment, although, TCE is in the vadose zone which causes groundwater contamination.	Ongoing voluntary action (soil vapor extraction) to remove TCE in the vadose zone. Remedial action alternatives developed in FS.
Meandering Road Creek (includes inlet to Lake Worth)	Silver exceeds ecological risk thresholds. Contaminants do not pose an unacceptable risk to human health.	Remedial action alternatives developed in the FS.

Table ES-1 (continued) Summary of Air Force Plant 4 Sites/Areas of Concern

Site	Findings	Voluntary Actions/ Proposed Action
Media: Groundwater		
Paluxy aquifer	TCE and 1,2-DCE cause unacceptable human health risk in two areas: (1) East plume under the East Parking Lot. (2) West plume under LF No. 3	Remedial alternatives developed in FS.
Upper Zone flow system - East Parking Lot Plume	TCE and DCE contamination is the source of contamination in the Paluxy aquifer. Suspected DNAPL at the Assembly Building and Window Area. Targeted for potential remedial action because of hydraulic connection to the Paluxy aquifer.	Ongoing voluntary actions at the East Parking Lot to extract and treat contaminated groundwater in the Window Area. Remedial alternatives developed in FS.
Upper Zone flow system - West Plume	Contaminants do not pose an unacceptable risk to human health or the environment.	Ongoing voluntary actions for groundwater include: 1. LF No.1: French Drains No. 1 and No. 2 to collect leachate. Leachate is treated at FSA-1 2. FSA-1: LNAPL recovery and groundwater extraction and treatment. 3. LF No. 3: Dual phase extraction to pump contaminated groundwater and extract VOCs from the vadose zone.
Upper Zone flow system - North Plume	Contaminants do not pose an unacceptable risk to human health or the environment.	Ongoing voluntary action at FSA -3 to remove LNAPL and extract and treat groundwater.
Media: Surface Water		
Meandering Road Creek	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Lake Worth	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned
Farmers Branch Creek	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.

1.0 Introduction

1.1 Purpose and Organization of Report

This Feasibility Study is a portion of the Remedial Investigation/Feasibility Study (RI/FS) process for the Air Force Plant No. 4 (Plant 4) located near Fort Worth, Texas. This document is intended to serve as the mechanism for development, screening, and evaluation of detailed alternatives for remedial action, whereas the greater RI/FS process is intended to gather sufficient information to support an informed risk management decision.

Information presented in the RI is summarized in this document. Remedial action needs are identified, based on the overall objective of protection of human health and the environment. Once identified, technologies applicable to the types, volumes, and extent of wastes were screened for appropriateness and combined into alternatives that will meet identified objectives. These alternatives for remedial action were then analyzed in detail. This report is organized in general conformance with the suggested FS outline published in the October 1988 Interim Final RI/FS Guidance (Environmental Protection Agency [EPA], 1988a).

1.2 Site Description

1.2.1 Location

The Plant 4 facility is located in Tarrant County, Texas, seven miles northwest of the city of Fort Worth (see Figure 1-1). Plant 4 is bounded on the north by Lake Worth, on the east by Carswell Air Force Base (CAFB), on the west by the city of Fort Worth, and on the south and west by the city of White Settlement.

1.2.2 Industrial Setting

Plant 4 occupies 602 acres and employs people in various positions pertaining to aircraft manufacturing and associated processes. Naval Air Station Fort Worth, formerly known as Carswell Air Force Base (CAFB) and hereafter referred to as CAFB in this report, lies directly adjacent to Plant 4 on the east. CAFB occupies about 2,800 acres and is currently on the base realignment and closure list. When the base was active it employed approximately 1,200 military personnel and 300 civilians.

1.2.3 Environmental Setting

Plant 4 and the surrounding areas to the south and east are highly urbanized and, consequently, do not contain natural vegetation for wildlife. Approximately 70 percent of the Plant 4 surface area is covered by buildings, concrete, or asphalt. The remaining 30 percent of the surface area is primarily grass-covered soils located on the radar range, Landfills No. 3 and No. 4, along Meandering Road

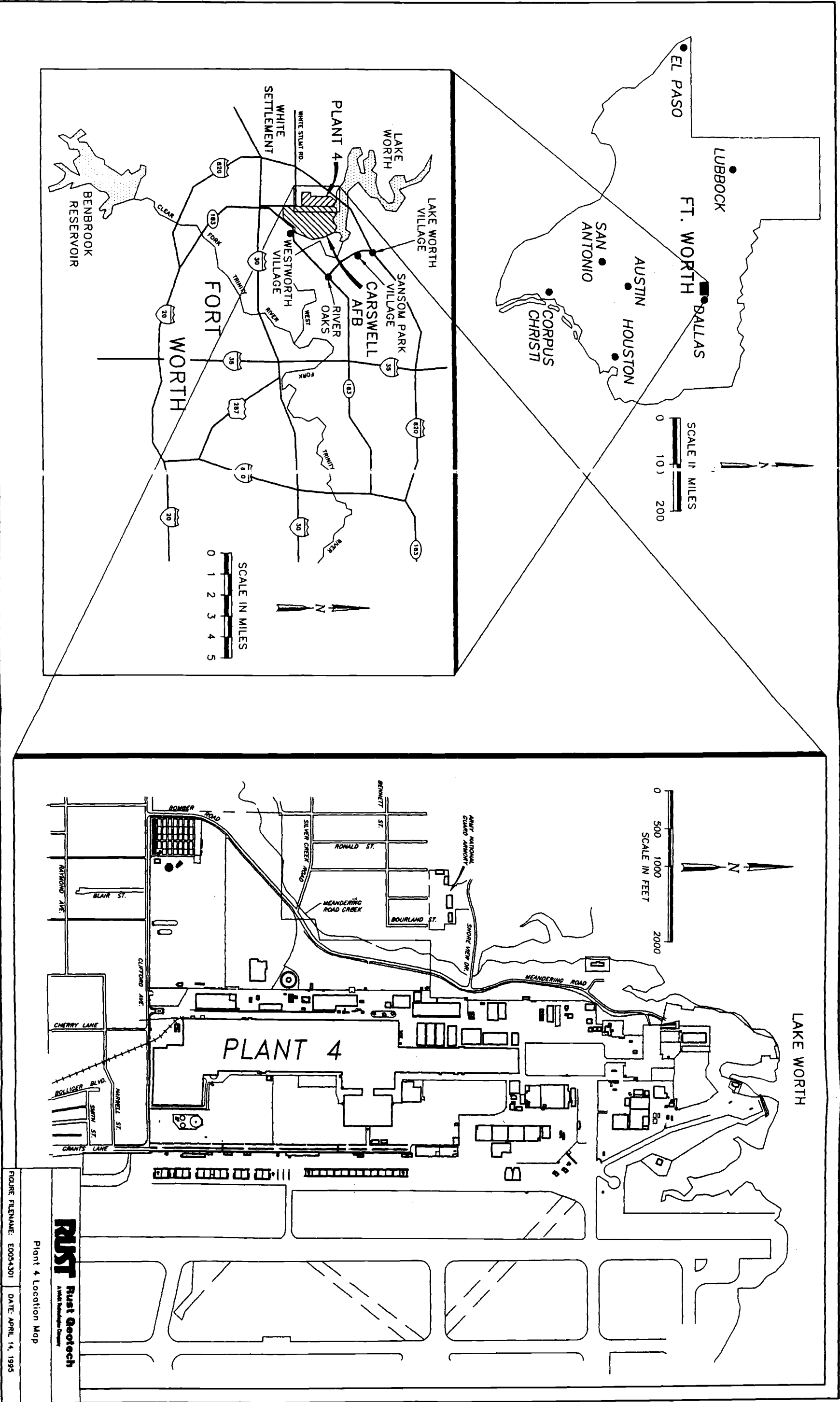


Figure 1-1. Plant 4 Location Map.

Creek, and along the shores of Lake Worth. The area to the west-northwest of Plant 4 contains primarily residential lots with an abundance of natural vegetation. Lake Worth, located north of Plant 4, provides recreational boating, fishing, and water skiing. The lake also provides municipal water to the city of Fort Worth and is a recharge source to the underlying Paluxy Aquifer that provides municipal water to the city of White Settlement.

1.3 Site History

Plant 4 became operational in 1942 when Consolidated Aircraft began manufacturing the B-24 bomber for national defense during World War II. In 1953, General Dynamics (GD) took over operation of the manufacturing facility. Since 1953, Plant 4 has produced B-36, B-58, and F-111 aircraft, and currently produces F-16 aircraft. In addition to F-16 aircraft, Plant 4 produces spare parts, radar units, and missile components. On March 1, 1993, Lockheed, Fort Worth Company, took over operations of Plant 4 as a successor to GD.

Manufacturing operations at Plant 4 have resulted in the generation of various hazardous wastes that include waste oils, fuels, spent solvents, paint residues, and spent process chemicals. Throughout most of the plant's history, waste oil, solvents, and fuels were disposed at on-site landfills or were burned during fire training exercises. Chemical wastes were initially discharged to the sanitary sewer system and treated by the city of Fort Worth's treatment system. In the 1970s, chemical process wastes were treated on site at a newly constructed chemical waste treatment system prior to being discharged to the sanitary sewer system. Currently, waste oils and solvents are disposed by a contractor, and burning of these wastes has been discontinued. Chemical wastes continue to be treated on site. Plant 4 was placed on the National Priorities List (NPL) in August 1990.

1.4 Physical Characteristics of the Study Area

1.4.1 Physiography

Plant 4 is located within the Western Cross Timbers Section and the Grand Prairie Section of the Central Lowlands Physiography Province. Most of Plant 4 is within the Grand Prairie Section, which is typically a broad, gently sloping terrace of sedimentary rock mantled by a thin layer of light brown to black loamy soil. The Grand Prairie Section is typically grass-covered with isolated stands of upland timber.

The northwest corner of Plant 4 lies within the Western Cross Timbers Section, which is characterized by rolling to hilly topography that is dissected into steep hills and deep ravines. The Western Cross Timbers Section is typified by sandy soils supporting a heavy growth of post oak and blackjack oak.

Topography at Plant 4 is generally flat except for areas adjacent to Meandering Road Creek and Lake Worth. Elevations at the site range from 590 feet above mean sea level along the shore of Lake Worth to approximately 670 feet above mean sea level at the southwest corner of the site.

1.4.2 Cultural Geography

1.4.2.1 Land Use

Plant 4 is located in a highly urbanized area because of its close proximity to the city of Fort Worth (see Figure 1-1). Plant 4 is directly bounded on the west by the city of Fort Worth and on the west and south by the city of White Settlement. The portion of Fort Worth adjacent to Plant 4 contains residential and commercial properties. The city of White Settlement includes residential, commercial, and light industrial properties. The area is accessed by two major interstate highways, I-80 from the north and south, and I-30 from the east and west. Plant 4 is accessed directly from I-30 by State Highway 341.

1.4.2.2 Demography

The population of Tarrant County (Fort Worth metropolitan area) is approximately 1,170,000; 447,600 of which live in the city of Fort Worth. Numerous smaller communities (suburbs) make up the balance of the population. The communities of White Settlement, Lake Worth Village, Westworth Village, River Oaks, and Sansom Park Village lie within a three-mile radius of Plant 4 and have the following populations based on a 1990 census: White Settlement—15,472; Lake Worth Village—4,591; Westworth Village—2,350; River Oaks—6,580; and Sansom Park Village—3,928.

Residential housing is immediately adjacent to Plant 4 on the south and west sides. Six schools are within a two-mile radius of Plant 4, the closest school is 0.5 mile south of the facility. Lockheed, the operating contractor at Plant 4, is the largest employer in the Fort Worth metropolitan area with a work force of 19,200 people, followed by Bell Helicopter (8,000), and the city of Fort Worth (6,000).

1.4.3 Air Quality

Ambient air quality for Tarrant County and the Fort Worth metropolitan area is monitored routinely at several locations by the Texas Air Control Board (TACB) and local agencies. The parameters monitored include total particulates (PM₁₀), carbon monoxide (CO), sulfur dioxide (SO₂), ozone, nitrogen dioxide (NO₂), and lead. According to information received from the TACB (see Table 1-1), the 1991 attainment status for Tarrant County was as follows. The status for PM₁₀ was "Unclassified" because not enough data had been collected for classification. The maximum levels recorded for PM₁₀ ranged from 53 to 101 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) (Federal standard is 150 $\mu\text{g}/\text{m}^3$), and the annual averages ranged from 20.1 to 25.1 $\mu\text{g}/\text{m}^3$ (Federal standard is 50 $\mu\text{g}/\text{m}^3$). The status for ozone was "Nonattainment," and the one-hour maximum levels ranged from 0.15 to 0.17 parts per million (ppm) (Federal standard is 0.12 ppm). The status for CO, SO₂, and NO₂ was "Attainment," with levels recorded well below the Federal standards. The status for lead was "Not Designated" because the data had not yet been evaluated. Quarterly averages for lead levels were 0.02 $\mu\text{g}/\text{m}^3$ (Federal standard is 1.5 $\mu\text{g}/\text{m}^3$).

1.4.4 Meteorology

Plant 4 is located at approximately 32 degrees north latitude and 97 degrees west longitude in north-central Texas. The climate at the site is typified by hot summers and cool, dry winters.

Table 1-1. Air Quality of Fort Worth Area

MONITORING SITE								
	FEDERAL STANDARDS	Tarrant County	CAMS-13 (Northwest) Mescham Field	CAMS-18 (Downtown) 100 N. Pecan	CAMS-17 (TC-Keller) City of Keller	Worth Heights (Elem. School) 519 E. Butler	City FAA Site (Center Point) 13800 FAA Rd.	Geddes 5933 Geddes
TOTAL PARTICULATE (PM 10) Status Minimum (ug/m³) Maximum (ug/m³) Annual Average (ug/m³)	150 50	Unclassified				7 73 25.1	5 63 20.1	6 101 23.3
OZONE Status 1 Hr. Maximum (ppm)	0.125	Nonattainment	0.15		0.17			
CARBON MONOXIDE (CO) Status 2nd Highest Hr. (ppm) 2nd Highest 8 Hr. (ppm)	35 9	Attainment	5.3 3.3	5.6 4.5				
SULFUR DIOXIDE (SO2) Status 2nd Highest 3 Hr. (ppm) 2nd Highest 24 Hr. (ppm) Annual Average (ppm)	.5 .14 .03	Attainment	0.01 0.00 0.001					
NITROGEN DIOXIDE (NO2) Status Annual Average (ppm)	.053	Attainment	0.014					
LEAD Status 1st Quarter Mean (ug/m³) 2nd Quarter Mean (ug/m³) 3rd Quarter Mean (ug/m³) 4th Quarter Mean (ug/m³) Yearly Average (ug/m³) Yearly Maximum (ug/m³)	1.5 1.5 1.5 1.5	Not Designated		0.02 0.02 0.02 0.02 0.05		0.02 0.02 0.02 0.02 0.06		
ug/m³ - micrograms per cubic meter ppm - parts per million								

Area meteorological data were obtained from the meteorological station at CAFB. These data were used to summarize historical data collected between 1942 and 1990 (see Table 1-2) and to assess recent data collected hourly from April 1, 1991 through March 31, 1992 (see Figure 1-2 through Figure 1-4). Each of these data sets is discussed separately below.

1.4.4.1 Summary of Historical Data

As shown in Table 1-2, the mean annual temperature in the vicinity of Plant 4 is 66 degrees Fahrenheit (°F). Mean monthly temperatures range from 45°F in January to 86°F in July. Extreme low and high temperatures have been reported at 0 and 110°F, respectively. Typically, the cooler months include December through February when average daily maximum temperatures range from 55 to 60°F and average daily minimum temperatures range from 35 to 39°F. The warmer months include June through August when average daily maximum temperatures range from 94 to 96°F, and average minimum temperatures range from 72 to 76°F.

Mean annual precipitation is 31.6 inches, with some precipitation occurring every month. Average monthly precipitation amounts are highest from April through May, ranging from 3.8 to 4.4 inches, and from September through October, ranging from 3.2 to 3.6 inches. Average monthly precipitation amounts are lowest from November through February, ranging from 1.7 to 1.8 inches, and during August when the monthly average is 1.9 inches. Thunderstorms may be expected every month; however, thunderstorms occur most frequently during spring and summer.

Precipitation typically consists of a mixture of rain and snow during the late fall and winter months. Snowfall amounts are generally greatest in January and February, when average snowfalls of 1 inch may be expected. Although average snowfall amounts are typically low, snowfall amounts of up to 12 inches in 1 month have been recorded.

During most of the year the predominant wind direction is from the south. During the winter months (i.e., December through February) the predominant wind direction is from the north. Constant winds with an average speed of 7 knots are typical year round.

The average cloud cover in the area is 50 percent. Average relative humidity values range from 57 percent in July and August to 70 percent in May. Average relative humidity is 63 percent.

1.4.4.2 Recent Data

Figure 1-2 presents the temperature variations from April 1, 1991 to March 31, 1992. The highest maximum temperatures were reported in July and August, with maximum values ranging from about 90 to 100°F. The lowest minimum temperatures occurred between November and March, with minimum values ranging from about 25 to 45°F. The lowest temperature reported during the period was approximately 15°F in early February.

The magnitude of daily temperature fluctuations was generally lowest from late May to late September. During this period, maximum and minimum daily temperatures were relatively constant and the average magnitude of fluctuations between extremes was about 20°F. The magnitude of maximum and minimum temperature values, as well as fluctuations between extremes, were much more variable during the rest of the year. The greatest daily fluctuations between extremes were reported in November, when fluctuations of up to 60°F were observed.

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Table 1-2. Summary of Meteorological Data Collected from 1942 to 1990

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual	Years of Record
Avg. Temperature (°F)	45	50	57	57	74	82	86	85	78	68	56	48	66	46
Daily Max.	55	60	67	76	83	94	96	95	90	78	66	59	77	46
Daily Min.	35	39	46	56	64	72	76	75	68	57	46	38	56	46
Highest Recorded	88	88	95	99	101	110	109	110	107	105	89	91	110	46
Lowest Recorded	2	5	11	31	42	55	61	60	43	33	17	0	0	46
Avg. Precipitation (Inches)	1.8	1.8	2.3	3.8	4.4	2.9	2.4	1.9	3.6	3.2	1.7	1.8	31.6	46
Monthly Max.	5.9	8.4	6.5	14.2	15.2	11.3	9	6	9.6	10.7	7.4	6.7	15.2	44
Monthly Min.	<0.05	0.1	<0.05	0.2	0.6	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	44
24-Hour Max.	2.8	3	3.4	3.3	5.7	3.5	5.9	3.1	4	3.2	2.8	2.9	5.9	44
No. Thunderstorms	1	2	4	6	8	6	5	5	4	3	1	1	46	46
Avg. Snowfall (Inches)	1	1	<0.05	0	0	0	0	0	0	0	<0.05	<0.05	2	43
24-Hour Max.	5	8	7	0	0	0	0	0	0	0	4	3	8	41
Monthly Max.	8	12	7	0	0	0	0	0	0	0	4	3	12	41
Avg. Wind Direction	N	N	S	S	S	S	S	S	S	S	S	N	S	10
Speed (Knots)	7	8	8	8	7	7	6	6	6	6	7	7	7	10
Cloud Cover (%)	60	60	60	50	60	60	40	40	50	50	60	60	50	10
Rel. Humidity (%) ^a	63	66	63	62	70	66	57	57	63	63	64	62	63	10

^a - calculated as an average of the morning and afternoon readings

Source: Carswell Air Force Base, Texas, Meteorological Station, 1942-1990

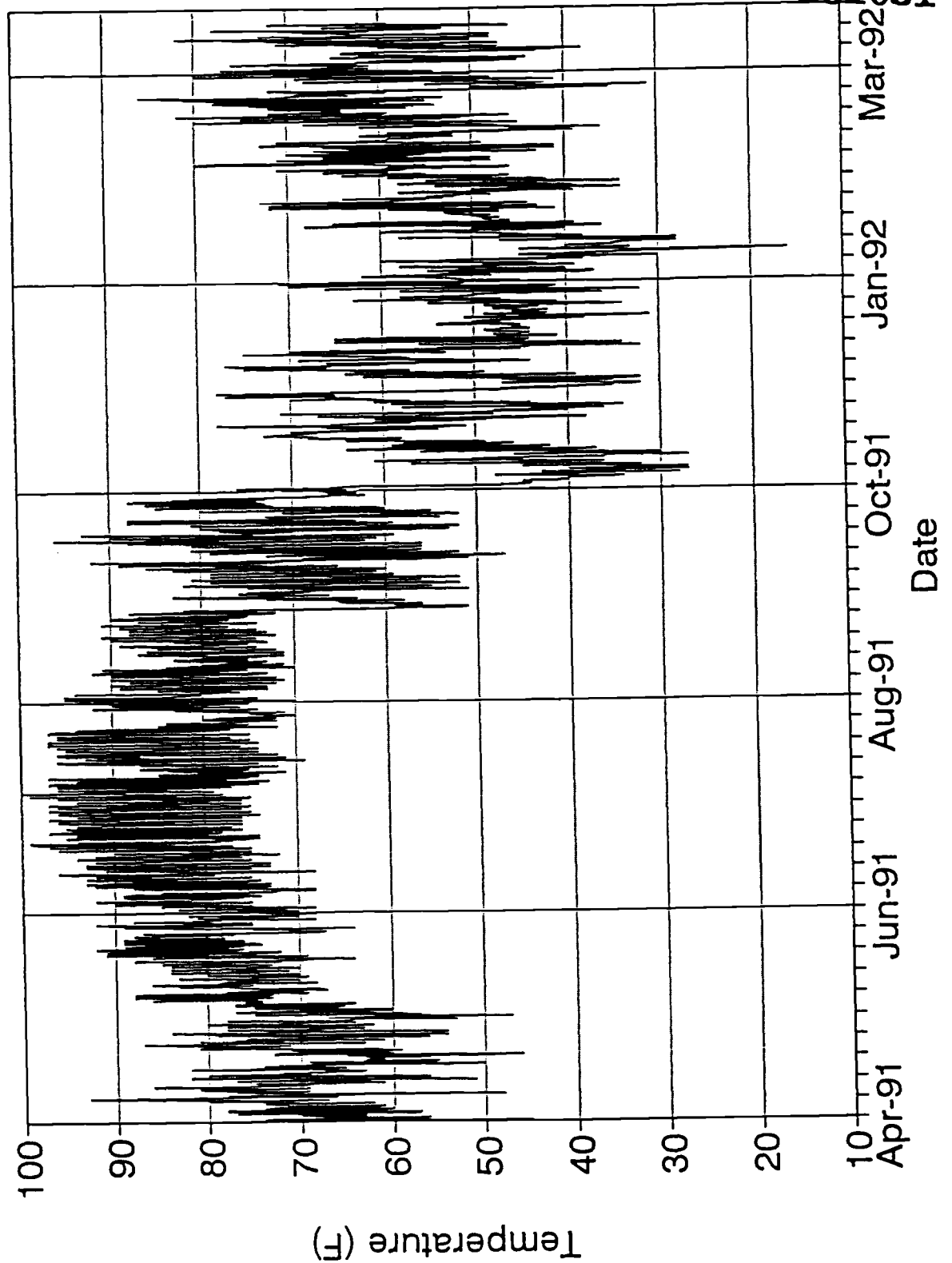


Figure 1-2. Distribution of Hourly Temperature Measurements from April 1991 to March 1992

Figure 1-3 shows the precipitation amounts reported from April 1, 1991 to March 31, 1992. As shown, some precipitation was reported each month. Storm events producing the greatest amounts of precipitation occurred in August (approximately 3.5 inches), November (approximately 4.5 inches), and December (approximately 3.5 inches). Except for these extremes, precipitation amounts generally ranged from less than 0.5 inch to about 1.5 inches. Storm events that produced measurable amounts of precipitation were reported most frequently during April, May, September, and December. The driest months during the period included July, October, and February.

Figure 1-4 shows the barometric pressure measurements reported from April 1, 1991 to March 31, 1992. Barometric pressures ranged from a low of about 28.80 inches of mercury in late April to a high of about 30.05 inches in November. Barometric pressures remained relatively constant during the summer months, ranging from 29.10 to 29.50 inches. Barometric pressures were most variable during the winter months, ranging from lows of 28.95 inches to highs of up to 30.05 inches.

1.4.5 Ecology

Because of the urban environment surrounding Plant 4, there are few natural terrestrial and aquatic communities in the area. However, Lake Worth with several small inlets along its boundary and Meandering Road Creek do support a limited complex of terrestrial and aquatic communities. The terrestrial community generally occupies a narrow strip of upland between the Plant 4 facilities and the creek and the lake; the aquatic communities include those of the creek, the inlets, and the lake (IT Corp. 1992).

The terrestrial ecosystem is characterized by upland sites where vegetation is dominated by native and introduced grasses (e.g., *Andropogon*, *Digitaria*, and *Cynodon*), and occasional oaks (*Quercus* spp.). Mice, gophers, squirrels, rabbits, granivorous and insectivorous birds, lizards, snakes, skunks, and higher predators such as hawks, owls, and foxes are expected to inhabit this community. Actual sightings in this community included foxes, rats, squirrels, and fire ants.

A well-developed, wooded riparian corridor approximately 50 to 100 feet wide occurs at the interface of the terrestrial community and the aquatic community of Meandering Road Creek. Here, oaks (*Quercus* spp.), hackberries (*Celtis* spp.), Osage-orange (*Maclura pomifera*), and wild roses (*Rosa* spp.) dominate the vegetative growth. Wildlife expected in the riparian community are amphibians, arboreal mammals, insectivorous birds, and animals that forage or prey near water, such as skunks, raccoons, and snakes. Actual wildlife sightings included gulls, ducks, cranes, passerine birds, snakes, turtles, and insects. Raccoon tracks were also observed in this area. The riparian community diminishes as the creek approaches Lake Worth; along the outer reaches of the creek's inlet and along the lake itself, there is an almost direct interface between the upland and lake communities, as the shoreline drops steeply into the water. Cattails, rushes, and other forms of wetland vegetation are absent from the lake shore.

Meandering Road Creek is an ephemeral stream fed mainly by stormwater runoff with some baseflow contributed by ground-water discharge (seeps) along the east side of the draw. High rainfall events periodically scour the streambed and help control the development of the aquatic community. Living components of the stream community include fish, macroinvertebrates, zooplankton, algae, and microbes. No submergent or emergent macrophytes were detected in the stream at the time of field

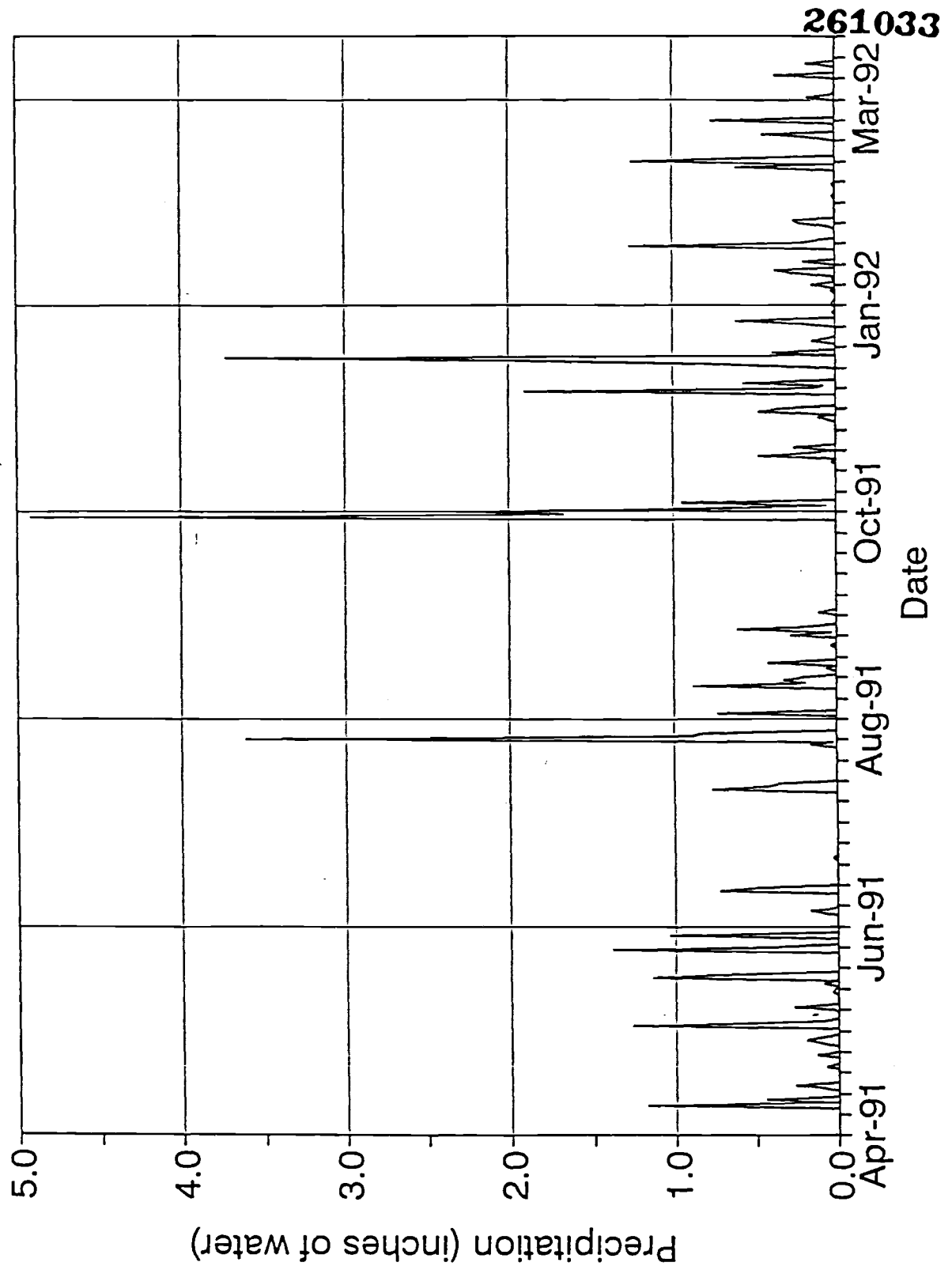


Figure 1-3. Distribution of Daily Total Precipitation Measurements from April 1991 to March 1992

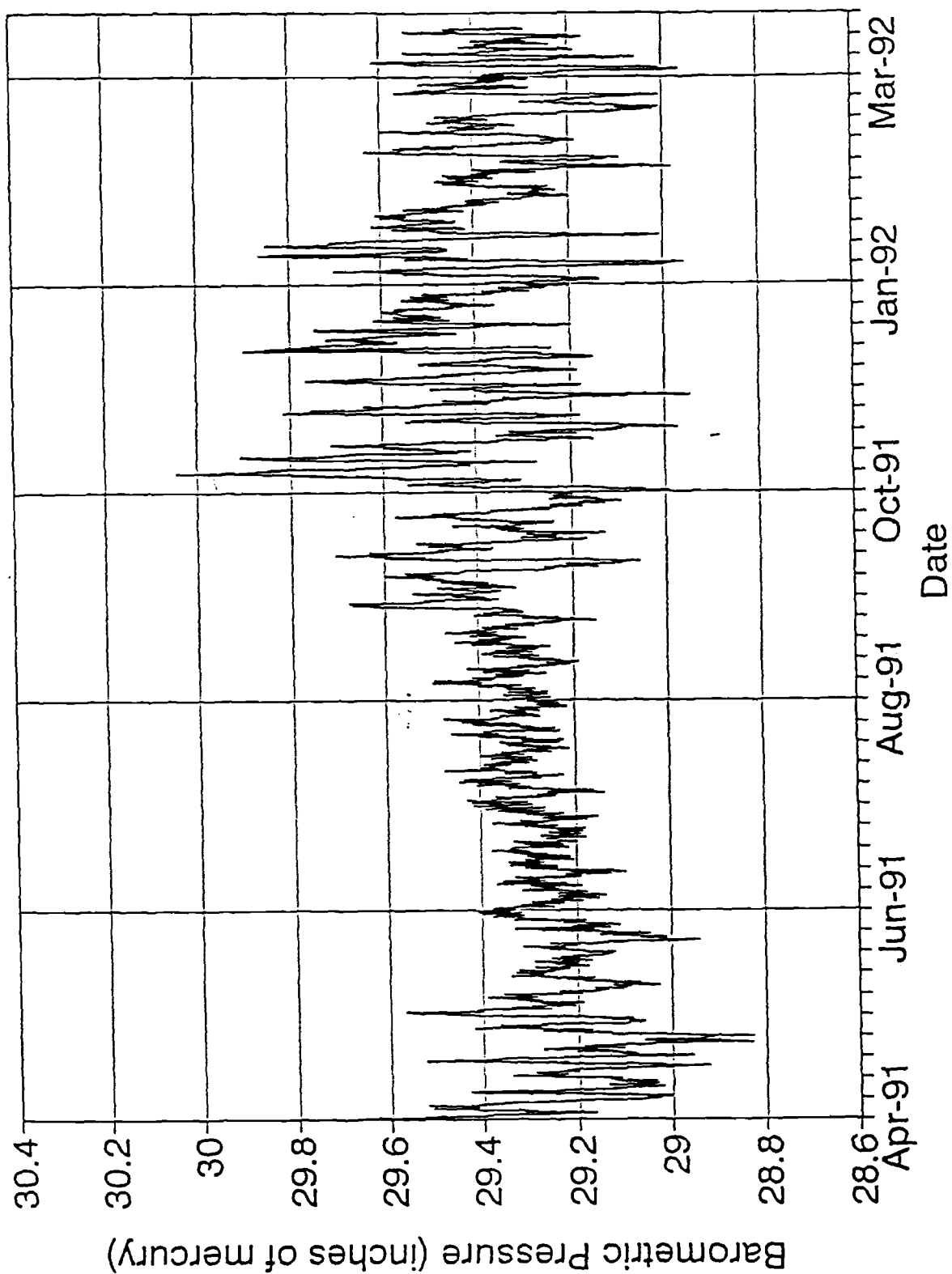


Figure 1-4. Distribution of Hourly Barometric Pressure Measurements from April 1991 to March 1992

sampling. The presence of small fish in pools indicated an active trophic system that is probably based both on detrital decay from the riparian and upland systems and on algal productivity.

The Meandering Road Creek inlet provides an interface between the stream and lake systems; four smaller inlets provide more direct interfaces between the terrestrial and lake systems. On occasion, inlet water quality may be significantly affected by direct contributions from adjacent terrestrial systems (and by flow from the creek, in the case of the Meandering Road Creek inlet), but in terms of community structure, the inlets are expected to be similar to Lake Worth. Biota of the inlet community include fish, turtles, macroinvertebrates, zooplankton, macrophytes, algae, and microbes.

Constructed in the early 1900s, Lake Worth is a steep-sided, relatively shallow (less than 30 feet deep) reservoir on the West Fork of the Trinity River. It is used for recreation and fishing, and as a domestic water supply. All trophic levels are expected in the aquatic food web of the lake, including predatory vertebrates (fish, turtles), macroinvertebrates, zooplankton, macrophytes, algae, and microbes. The transition between the inlet and lake systems is not well defined, and the extent of mixing has not been studied. However, it is expected that lake currents and mixing rates result in a gradient of ecological conditions from the main body of Lake Worth to the upper reaches of the inlets (IT Corp. 1992).

1.4.6 Surface Water Hydrology

The primary surface waters in the vicinity of Plant 4 include Lake Worth, Meandering Road Creek, and Farmers Branch and West Fork of the Trinity River (see Plate 2). Lake Worth extends along the northern boundary of the site. Meandering Road Creek borders the western site boundary and flows north to Lake Worth. Farmers Branch flows eastward near the southern boundary of the site and discharges into the West Fork of the Trinity River. The West Fork of the Trinity River flows southeastward from the Lake Worth dam and spillway. Each of the primary surface water features is described in further detail in the following sections.

1.4.6.1 Lake Worth

The Lake Worth reservoir was constructed in 1914 by the city of Fort Worth as a municipal water supply (U.S. Geological Survey [USGS] 1989). The reservoir was created by damming the West Fork of the Trinity River northeast of Plant 4. In addition to municipal water supply, the reservoir is also used for irrigation and recreation.

The reservoir was constructed with a dam elevation of 606.3 feet above mean sea level. According to Tarrant County Water Control and Improvement District Number One daily gauge records, the dam spillway was originally constructed at an elevation of 594.3 feet above mean sea level; however, the elevation of the dam spillway was modified and lowered to 594 feet above mean sea level in 1980. At full capacity, the reservoir averages six feet in depth, with a maximum depth of 28 feet, and covers approximately 3,560 acres with 37,066 acre-feet of storage. The spillway has a maximum discharge capacity of 55,000 cubic feet per second. The drainage area associated with Lake Worth covers approximately 2,064 square miles (USGS 1989).

Historically, silt accumulation was recognized as a problem in Lake Worth. The silting problem was significantly reduced in 1934 following completion of two upstream reservoirs: Bridgeport and Eagle Mountain. Because the reservoir was never dredged, large silt accumulations may exist. Through

adsorption, these accumulations would significantly impact the fate of chemical constituents present in the lake.

The Tarrant County Water Control and Improvement District Number One maintains reservoir records that include information on precipitation, stage heights, diversion quantities, and flood gauging from 1920 to the present. Review of records from water years 1940 to 1991 indicate that releases over the spillway may occur at any time of the year. During the 1940s, the reservoir had a constant net release; from approximately 1948 to present, the average annual stage height has typically been below the spillway. Estimated average annual storage values for the period ranged from 23,746 acre-feet in 1956 to 38,664 acre-feet in 1942.

1.4.6.2 Meandering Road Creek

Meandering Road Creek borders Plant 4 to the west and flows north to Lake Worth. Meandering Road Creek is an intermittent stream receiving the majority of its flow from surface water runoff discharged into the creek via storm drains and culverts. Several seeps were identified along the east bank of the creek during field reconnaissance. The presence of these seeps indicates that Meandering Road Creek also receives some baseflow from ground water.

1.4.6.3 Farmers Branch

Farmers Branch originates in White Settlement and flows south of Plant 4 in an easterly direction to the West Fork of the Trinity River. Like Meandering Road Creek, Farmers Branch is an intermittent stream that receives most of its flow from surface water runoff discharged into the creek via storm drains and culverts. Comparison of water-table elevations in the vicinity of Farmers Branch with a topographic profile of the stream indicates that Farmers Branch may receive some recharge from ground water.

1.4.6.4 West Fork of the Trinity River

Near Plant 4, the West Fork of the Trinity River flows in a southeasterly direction from the Lake Worth dam and spillway. Flow in the West Fork of the Trinity River is largely controlled by releases from Lake Worth. However, some flow is attributed to surface water runoff that reaches the stream via tributaries. Water table elevations near the stream (see Figure II-26 of the RI) suggest that the West Fork of the Trinity River may receive recharge from the upper-zone ground-water system.

1.4.6.5 Evaluation of Flood Potential

In 1982, the Federal Emergency Management Agency (FEMA) requested a flood insurance study to investigate the existence and severity of flood hazards in the unincorporated areas of Tarrant County, including the area in the vicinity of Lake Worth. This study physically delineated theoretical flood events, such as the 100- and 500-year flood. Results of the study estimated that stage heights for the 100-year flood will be 599.9 feet and approximately 602.7 feet for the 500-year flood (FEMA 1987). These values equate to stage heights over the spillway of 5.9 feet and 8.7 feet, respectively. According to reservoir records obtained from the Tarrant County Water Control and Improvement District Number One, the historical stage height nearest to the projected events was 4.17 feet over the spillway, recorded on May 25, 1957.

Delineations of the projected extent of the 100- and 500-year flood plains in the vicinity of Plant 4 are shown in Figure II-11 of the RI. These delineations are consistent with the estimated Lake Worth stage heights presented in the 1987 FEMA study. Areas where the extent of the 100- and 500-year flood events closely correspond are designated as the combined 100- and 500-year flood event in Figure II-11 of the RI. As shown, neither the 100- nor 500-year flood event will directly impact Plant 4. Therefore, flooding is not considered a likely mechanism for transport of chemicals from the site. In addition, protection against flooding may not be a design consideration during implementation of any future on-site remedial actions.

Meandering Road Creek, located west of the Plant 4 boundary, is impacted by the 100-year flood. One-hundred-year flood waters are estimated to extend approximately 900 feet upstream from the mouth of Meandering Road Creek. Therefore, any chemicals present in sediment and surface soil within this area could potentially be transported to the Lake Worth system through submersion and erosion. Any future remedial actions within the projected extent of the 100-year flood event will require design consideration for protection against flooding.

The remaining primary surface waters in the area, Farmers Branch and the West Fork of the Trinity River, are both impacted by the projected extent of the 100- and 500-year flood events. Both the 100- and 500-year flood events are estimated to extend approximately 1,600 feet upstream from the mouth of Farmers Branch. The extent of flooding along the West Fork of the Trinity River would be most pronounced in the area immediately below the Lake Worth dam. Any chemicals present in sediment and surface soil within the projected extent of flooding along these surface waters could potentially be transported downstream along the West Fork of the Trinity River.

1.4.7 Geology

1.4.7.1 Regional Geologic and Structural Setting

The bedrock geology of west-central Tarrant County is characterized by sedimentary rocks of the Early Cretaceous period underlain by undifferentiated rocks of the Paleozoic era. Unconsolidated thin alluvial deposits of the Quaternary period cover bedrock in and near major stream and river valleys.

The sedimentary rocks in the site area were deposited in a stable structural setting on the Texas craton. Figure 1-5 shows the structural features and their proximity to the site in Tarrant County. Those features include the Mexia-Talco fault system about 80 miles to the east, the front of the Ouachita overthrust about 30 miles to the east, and the south end of the axis of the Fort Worth basin, located directly under the site, in which sediments accumulated during most of the Paleozoic era.

In the latter part of the Paleozoic era, during the Permian period, the site area was uplifted and the extensive erosion that occurred through the Jurassic period produced a flat surface upon which early Cretaceous period marine sediments (Comanchean Series) were deposited along an oscillating shoreline. The marine sediments are preserved as a southeast-thickening wedge of rocks extending from the site area into the East Texas basin (see Figure 1-5). From the Late Cretaceous period through the Tertiary period, the sea withdrew toward the gulf, and, except for minor periods of subsidence, the land surface was eroded and modified by streams. During the Quaternary period, the streams deposited alluvial sediments. The older sediments are represented by terrace deposits above the alluvial-filled valleys of present streams.

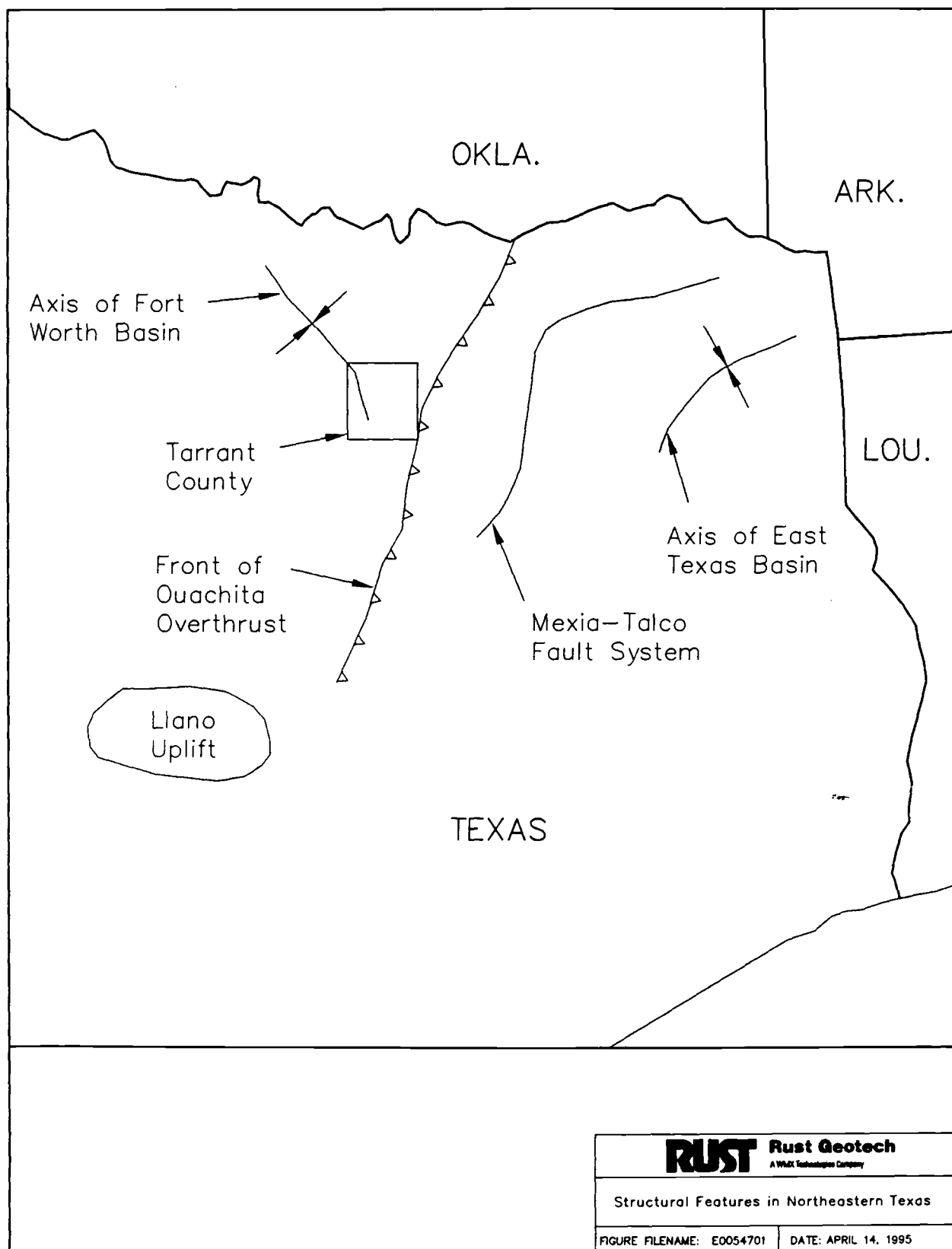


Figure 1-5. Structural Features in Northeastern Texas
(modified from Nordstrom, 1982).

Table 1-3 lists the regional stratigraphic units of interest in the vicinity of Plant 4. These units are described in the following section in descending order, from youngest to oldest.

Table 1-3. Stratigraphic Units of Interest in the Vicinity of Plant 4

Era	System	Series	Group	Stratigraphic Units
Cenozoic	Quaternary	Holocene		Fill Material Alluvium
		Pleistocene		Fluvial Terrace Deposits
	Tertiary			
Mesozoic	Cretaceous	Gulf		
		Comanche	Washita	Duck Creek Limestone Kiamichi Formation
			Fredericksburg	Goodland Limestone Walnut Formation
			Trinity	Paluxy Formation Glen Rose Formation Twin Mountains Formation
Paleozoic				Paleozoic Rocks Undifferentiated

Unconsolidated alluvial sediments and fill material overlie Cretaceous period rocks and consist of Holocene epoch fill material and flood plain deposits and Pleistocene epoch terrace deposits. The fill material on and adjacent to the Plant 4 site was emplaced since the 1940s and consists of general refuse and construction debris (i.e., lumber, asphalt, metal, concrete, glass, and plastic) mixed with gravel, sand, silt, and clay. The flood plain deposits consist of alluvium (i.e., gravel, sand, silt, silty clay, and organic material) that fill present stream and river valleys. The Pleistocene epoch terrace deposits occur above the present stream valleys and consist of gravel, sand, and silt that represent older flood plain deposits.

Lower Cretaceous period rocks consist of the Washita, Fredericksburg, and Trinity Groups (see Table 1-3) all of which dip gently toward the east-southeast at approximately 0.4 degrees or 37 feet per mile (Leggat 1957). Rocks of the Washita Group occur south and east of Plant 4; the two lowermost formations in the group, Duck Creek Limestone and Kiamichi Formation, form the hilltops and hillsides, respectively, about 1 mile east and south of the plant. The Duck Creek Limestone consists of gray, aphanitic, fossiliferous limestone that is 30 to 100 feet thick (McGowen and

others 1988). The slope-forming Kiamichi Formation is from 20- to 50-feet thick and consists of alternating brown clay and gray, aphanitic, fossiliferous limestone beds (McGowen and others 1988).

Rocks of the Fredericksburg Group, which consist of Goodland Limestone and the conformably underlying Walnut Formation, crop out in Plant 4 or underlie most of the site. The Goodland Limestone forms low, rounded hills and buttes, and upland surfaces capped by terrace material and is usually well-exposed on steep, west-facing escarpments. The Goodland Limestone comprises white, chalky, fossiliferous, thinly to massively bedded, resistant limestone, and gray to yellow-brown silty marl. The formation is extensively jointed and ranges from 0 to 130 feet thick in Tarrant County (Leggat 1957). West of the Plant 4 area, the Walnut Formation forms resistant ridges of indurated fossiliferous limestone and shell coquinite. Included in the formation, which is an average of 30 feet thick, are interbedded brown sandy clay, thinly bedded fossiliferous clay, fissile shale, and iron-stained earthy limestone (Leggat 1957).

Rocks of the Trinity Group, which consist of the Paluxy, Glen Rose, and Twin Mountains Formations, crop out west of Plant 4 and underlie the site. The Paluxy Formation, disconformably separated from the overlying Walnut Formation, forms the bed of Lake Worth and consists of sandstone and siltstone interbedded with sandy to silty, calcareous, waxy clay and shale (Nordstrom 1982). The sandstone, composed of fine- to coarse-grained white quartz, is well-sorted, poorly consolidated, and cross-bedded. Iron and pyrite nodules occur in the sandstone, and lignite is locally present. The thickness of the Paluxy Formation in Tarrant County ranges from 140 to 190 feet (Leggat 1957). Conformably underlying the Paluxy Formation is the Glen Rose Formation that consists of sandstone, clay, sandy clay, limestone, and anhydrite. In the Lake Worth area, the Glen Rose Formation is approximately 250 feet thick. The Twin Mountains Formation (formerly the Travis Peak Formation) is overlain conformably by the Glen Rose Formation. The Twin Mountains Formation grades upward from a basal conglomerate of chert and quartz to a fine- to coarse-grained sandstone interbedded with shale and clay (Leggat 1957). The thickness of the Twin Mountains Formation is approximately 250 feet below Lake Worth with increasing thickness to the east.

Undifferentiated Paleozoic-era rocks are overlain unconformably by the Twin Mountains Formation. The Paleozoic-era rocks are 6,000 to 7,000 feet thick and consist of well-indurated shales, sandstones, and limestones.

1.4.7.2 Site Geology

Figure 1-6 shows the surface geology of an approximate 16-square-mile area that surrounds and includes the Plant 4 site. The geologic map presented in the figure is part of the larger geologic map of central Tarrant County, published at 1:24,000 scale on an aerial photograph base map by the Fort Worth Geological Society (Rogers and others 1972). Several spot field checks were performed to verify the accuracy of the mapped geologic contacts. Minor modifications were made to the existing map to add a thin strip of Paluxy Formation outcrop along the shore of Lake Worth northwest of Plant 4 and a narrow band of Paluxy Formation outcrop along Meandering Road Creek just south of Lake Worth.

Geologic units that are of concern at the site were penetrated by monitoring wells and soil borings; these units include, in descending order, fill material, alluvium, terrace deposits, Goodland Limestone, Walnut Formation, and Paluxy Formation. The following sections describe the physical characteristics and thickness of each of these units around the site.

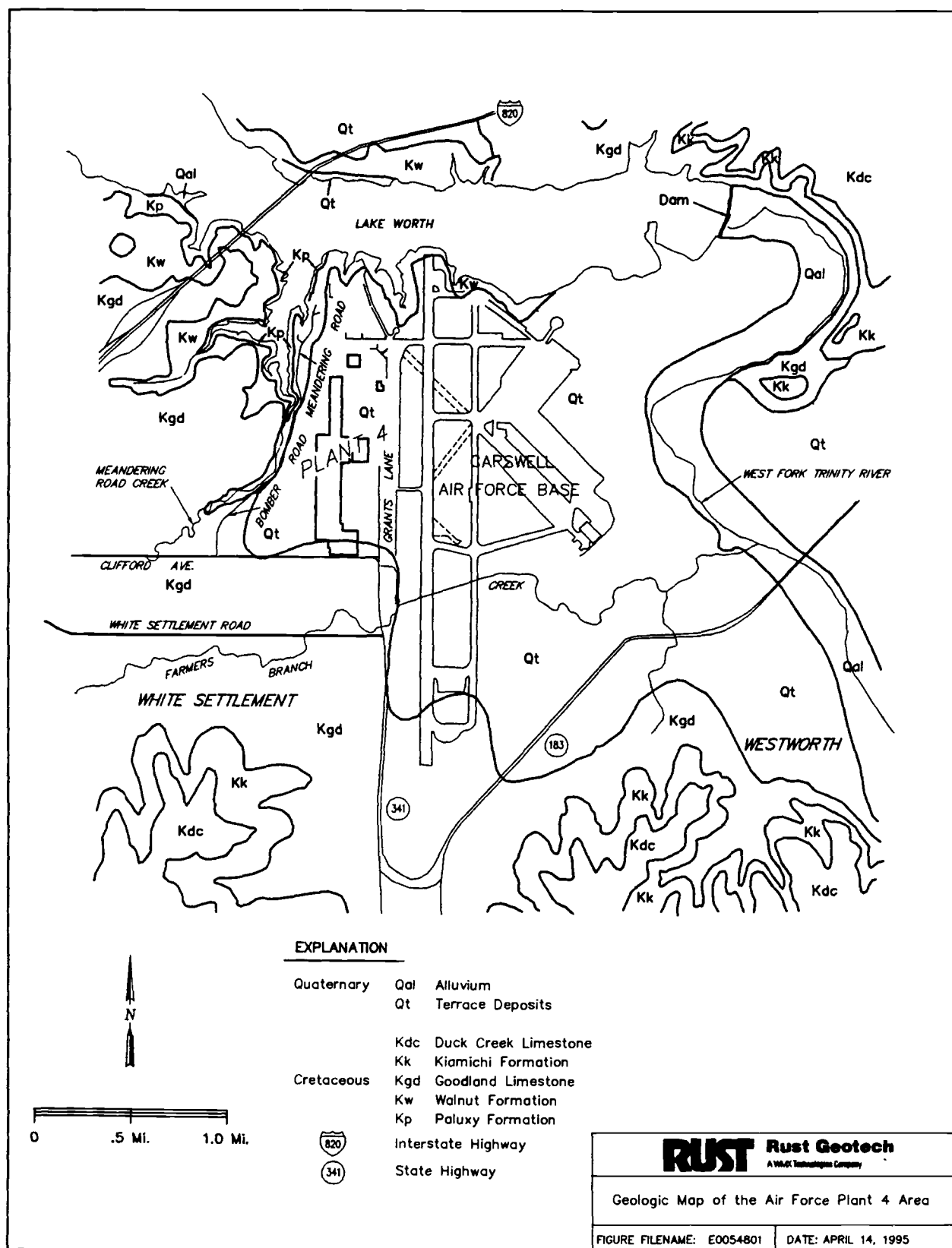


Figure 1-6. Geologic Map of the Air Force Plant 4 Area.

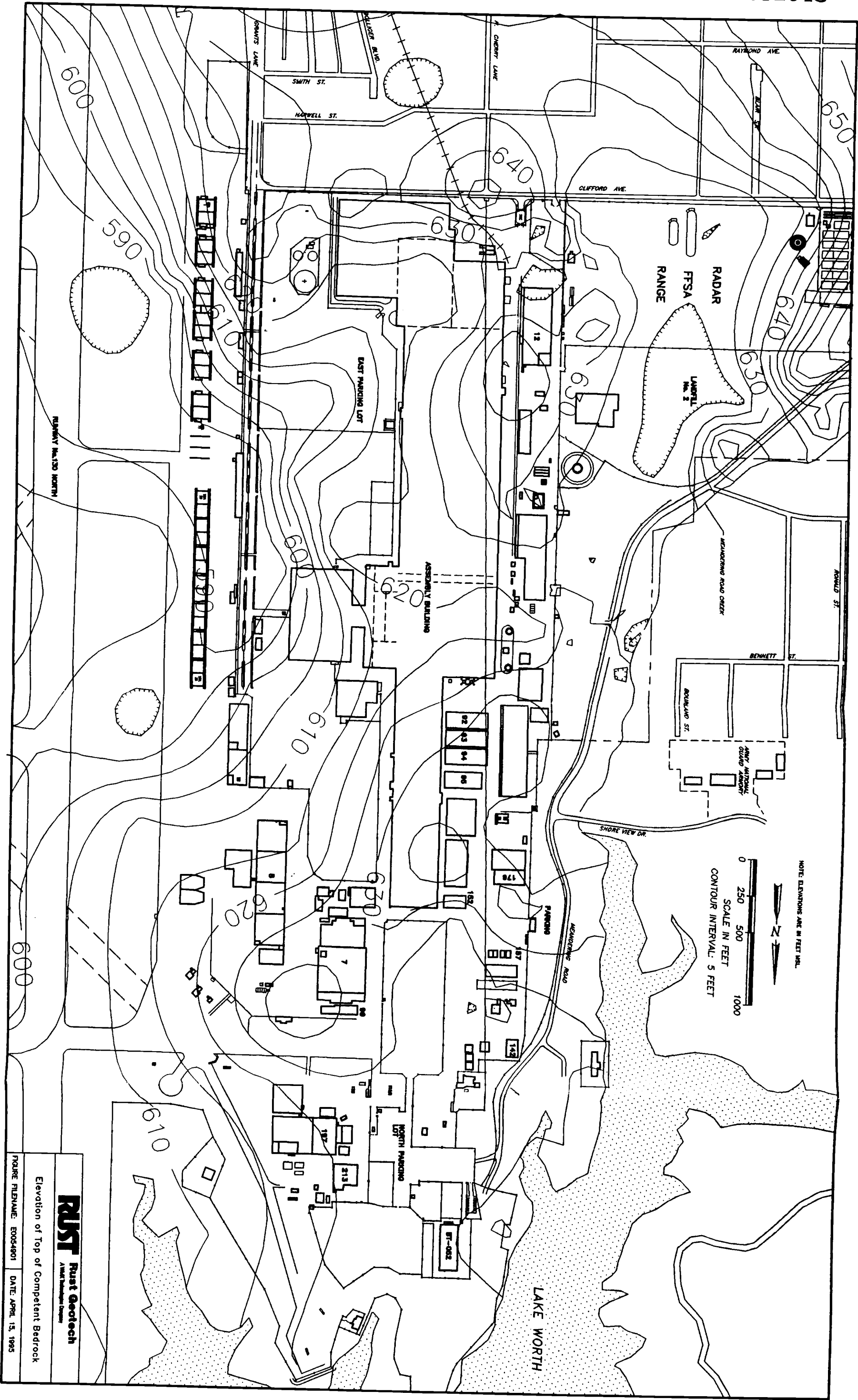
Quaternary period alluvium that occurs downstream from the Lake Worth dam in the present flood plain of the West Fork of the Trinity River, east of Plant 4 and CAFB, is mainly of the Holocene or Recent epoch (see Figure 1-6). Older alluvial deposits and the terrace deposits of mainly the Pleistocene epoch cover most of the nearly flat surface that tilts gently to the east. Plant 4 and CAFB occupy most of this flat surface, which continues eastward to the flood plain of the West Fork of the Trinity River and includes part of Westworth Village.

Fill material is included in the area mapped as terrace deposits in both Plant 4 and CAFB. The fill occurs in abandoned landfills, waste pits, excavated areas, and where the land surface was graded or altered for construction of buildings, parking lots, and other paved areas such as runways (Hargis + Associates 1989b). The fill material generally comprises unconsolidated mixtures of clay, silt, sand, and gravel but may also contain general refuse, chemical sludge, and construction debris (i.e., lumber, asphalt, metal, concrete, glass, and plastic). Fill material is particularly common along the west side of Plant 4 in Landfill Nos. 1 through 4 where the fill may be up to 20 feet thick. In these landfills, fill material replaced terrace deposits that were removed or fill was dumped on the slope at the edge of the terrace. In some places, fill material extends down to bedrock.

The unconsolidated terrace alluvial material is poorly to moderately sorted and is composed of heterogeneous interbedded clay, silt, sand, and gravel. Individual beds are not laterally continuous. Most of the clastic material (which ranges up to cobble size) in these sediments consists of limestone and fossil shell fragments; sand grains composed of quartz are a minor constituent.

Terrace deposits and/or fill material are present over most of the area of Plant 4 and CAFB. Fill and terrace material are not present along some of the west edge of Plant 4 where the Walnut Formation crops out and in parts of the south end of Plant 4 where the Goodland Limestone crops out (see Figure 1-6). The thickness of the terrace/fill varies considerably around Plant 4. The thickest accumulations are up to about 50 feet in the area of the Radar Range and up to nearly 60 feet in the east part of the East Parking Lot. These thickness variations indicate the presence of valleys and hills on the bedrock surface. The valleys have been eroded mainly into the Goodland Limestone and the Walnut Formation.

The general configuration of the bedrock surface upon which the terrace alluvial material was deposited may be inferred from the computer-contoured map that shows the elevation of the top of competent bedrock (see Figure 1-7), which corresponds to the base of the upper zone. The thickness of weathered bedrock above the competent bedrock ranges from zero to as much as 10 feet. Figure 1-7 shows the positions of three troughs or channels where the thickest accumulations of terrace material are located. The first channel is located beneath the southern end of the Assembly Building and extends to the northeast, beneath the East Parking Lot, and then southeast beneath the flightline (Runway No. 130 North). In the vicinity of the flightline area, the channel apparently splits with the main link extending to the southeast. A cross section presented in the Interim Remedial Investigation Report (Hargis + Associates 1989a) and the cross sections in Figures II-1, II-2, and II-8 of the RI show that this channel cut down nearly through the entire thickness of the Walnut Formation. The second channel extends north from the Former Fuel Saturation Area (FFSA) to Landfill No. 2. These two troughs are likely the expression of meander bends that mark the former position of the West Fork of the Trinity River. A third trough is subtle and extends east and southeast from FDTA-2 toward the Assembly Building/Parts Plant.



Coarse sand and gravel deposits occur immediately above bedrock in several areas on Plant 4 and CAFB. The greatest thickness of these coarse deposits is in the troughs where the gravels were deposited as channel lag on the scoured bedrock surface. The trough near the FFSA contains basal sand and gravel at least 20 feet thick. Basal sand and gravel in the trough in the East Parking Lot area reaches a thickness of at least 15 feet (Hargis + Associates 1989a). Basal sand and gravel in the southeastward extension of this trough under the runways at CAFB range up to at least 35 feet thick. Sand and gravel greater than 20 feet thick at CAFB occurs in an 800-foot-wide area that trends eastward approximately in line with White Settlement Road. These deposits probably coincide with the location of a former channel of what is now Farmers Branch Creek (Radian Corporation 1990).

Goodland Limestone

Rocks of the lower Cretaceous period Goodland Limestone (the upper member of the Fredericksburg Group) crop out in only a few small areas in the south and southwest parts of Plant 4 and CAFB (see Figure 1-6). The Goodland Limestone is present in the subsurface at Plant 4 and CAFB, except where erosion has removed it in the northwest part of Plant 4, the north part of CAFB, and in deeply eroded meander bends cut by former courses of the West Fork of the Trinity River beneath both Plant 4 and CAFB.

The top of the formation is highly weathered in places because it was exposed for a long period prior to deposition of overlying Quaternary period alluvial deposits. The thickness of the formation on the site is variable, depending on the amount of erosion that has occurred. The thickest Goodland Limestone encountered in the site area (just west of Plant 4 at well EPA-4) is 47 feet. For wells within Plant 4, the maximum thickness of Goodland is 20 to 25 feet, as shown in cross sections in the Interim Remedial Investigation Report (Hargis + Associates 1989a).

The Goodland Limestone consists of chalky white, fossiliferous, dense, thinly to massively bedded limestone interbedded with gray to yellow-brown stiff clay and marl. The formation forms prominent white escarpments along streams, an example of which is the outcrop near well EPA-4 on the steep slope just east of Meandering Road Creek. Extensive jointing is exposed in this outcrop; however, core samples from the Goodland Limestone indicate that joints are rare in unweathered limestone. No subsurface faults are known to occur in the Goodland Limestone in the vicinity of Plant 4 (Hargis + Associates 1989b).

Walnut Formation

The Lower Cretaceous period Walnut Formation (the lower member of the Fredericksburg Group) underlies most of Plant 4 and CAFB. The formation crops out in the low cliffs along the Lake Worth shore north and northwest of Plant 4 and along Meandering Road Creek west of Plant 4 (see Figure 1-6).

Where erosional channels have not been cut into the top of the Walnut Formation, the thickness of the formation at Plant 4 is fairly constant and varies between 25 and 35 feet. The maximum reported thickness of the Walnut Formation in the Plant 4 area (at well P-1 between Clifford Avenue and the Assembly Building) is 46 feet (Hargis + Associates 1989b). A reinterpretation of the thickness of the Walnut Formation from the lithologic log from well P-1 places the thickness of the Walnut Formation at about 30 feet, which is similar to the Walnut Formation thickness at nearby well P-26.

The configuration of the top of the Walnut Formation at Plant 4 was shown previously (Hargis + Associates 1989b, Figure 5). Except for the deep channel cut into (and possibly through) the Walnut Formation in the East Parking Lot, the top of the Walnut Formation shows few abrupt changes in elevation. A reinterpretation of the sharp rise or knob in the top of the Walnut Formation south of Building 12 (Hargis + Associates 1989b, Figure 5) shows the feature is unsubstantiated because the wells (HM-3A, HM-4A, and F-221) on the feature did not penetrate deep enough to contact the Walnut Formation.

The three cross sections in the Interim Remedial Investigation Report (Hargis + Associates 1989a, Figures 6, 7, and 8) and the cross sections in Figures II-1 through II-10 of the RI show the thickness of the Walnut Formation throughout Plant 4. Water levels shown on the Volume II cross-sections (Figures II-1 through II-10 of the RI) are based on September 1991 or the most recent September/October water-level measurements. The cross section through the south edge of Plant 4 by Hargis + Associates (1989a, Figure 8) does not show the thick knob of Walnut Formation shown in the earlier Hargis + Associates report (1989b, Figure 5); therefore, the Walnut Formation thickness in this part of the site is characterized as fairly constant. The north-oriented cross section in the report by Hargis + Associates (1989a, Figure 6) and Figures II-1, II-2, and II-8 of the RI show the abrupt decrease in thickness of the Walnut Formation in the East Parking Lot area where the former river channel cut through most of the Walnut Formation. It is possible that the former channel has cut entirely through the Walnut Formation and into the underlying Paluxy Formation in the East Parking Lot area; however, no lithologic data from wells and soil borings confirm this.

The northwest-oriented cross section in the report by Hargis + Associates (1989a, Figure 7) suggests that in the northwest end of the section, Meandering Road Creek has cut through the entire thickness of the Walnut Formation. Determination of the base of the Walnut Formation from lithologic logs for wells located both east (wells P-22 and P-24) and west (wells P-10 and P-29) of lower Meandering Road Creek indicates that contact with the underlying Paluxy Formation is at an elevation of 600 feet. This suggests that the lower section of Meandering Road Creek has cut through the entire thickness of the Walnut Formation for a distance of about 1,000 feet before it empties into Lake Worth, which is normally at an elevation of 593 to 594 feet. However, a field inspection along the lowermost reach of Meandering Road Creek did not identify the basal contact of the Walnut Formation and the underlying Paluxy Formation in the creek bed because of thick cover and absence of outcrops.

The Walnut Formation, also referred to as Walnut "Shell" (Rogers and others 1972) and Walnut Clay (McGowen and others 1988), is mainly a shell agglomerate or coquinite that contains abundant *Gryphaea marcoui* and *Exogyra texana* (Leggat 1957). The coquinite often has a matrix of calcareous shale and clay. Interbeds of calcareous shale and clay also occur. Black, fissile shale was encountered in several boreholes from the upper part of the formation just above the coquinite. Dense sandy limestone, silty shale, and minor pyrite also occur in the lower part of the formation.

A disconformity separates the base of the Walnut Formation from the top of the Paluxy Formation. No faults or prominent fractures are known to occur in the Walnut Formation.

Paluxy Formation

The Paluxy Formation, commonly called the Paluxy Sand, is the upper member of the Lower Cretaceous period Trinity Group. The Paluxy Formation underlies all of Plant 4, and its uppermost part crops out along the Lake Worth shoreline just northwest of Plant 4.

The thickness of the Paluxy Formation ranges from 133 to 175 feet in the Plant 4 area (Hargis + Associates 1989b). The formation predominantly consists of several thick sandstone layers (cumulatively, about 120 feet thick in this area) separated by thin, discontinuous shale and claystone layers. The lower part of the Paluxy Formation is generally coarser grained than the upper part. The top of the underlying Glen Rose Formation is defined as the first occurrence of a limestone unit.

In the Plant 4 area, the Paluxy Formation was deposited as a strandplain facies, which consists largely of sandstone (Caughey 1977). This intercalated sandstone and shale sequence was deposited as a shifting complex of near-shore (littoral) environments on the western margin of the East Texas embayment.

Sandstones in the Paluxy Formation are porous, fine- to very-fine grained, and composed of moderately to well sorted, subangular to subrounded, white quartz sand. The sandstones are poorly cemented (friable) to slightly indurated with sparry calcite cement (Caughey 1977). Traces of pyrite, iron oxides (limonite concretions), and glauconite occur in the sandstone, and these can be locally abundant. Thinner sandstone beds tend to be the most diverse and contain pyrite nodules, traces of lignite, silicified wood, and carbonized plant fragments. The sandstones commonly exhibit low-angle cross-bedding. This cross-bedding was observed in core from the Paluxy Formation and in outcrop along the Lake Worth shoreline northwest of Plant 4 where horizontal fossiliferous limestone beds of the Walnut Formation truncate cross-bedded yellow-brown sandstone of the upper Paluxy Formation.

Bedding in the gray to green-gray or olive green shales (mudrocks) and silty claystones of the Paluxy Formation may be horizontally laminated, massive, or burrowed (churned or bioturbated). The mudstones commonly contain carbonized plant fragments and thin beds of lignite.

The thicknesses of individual sandstone and shaley units in the Paluxy Formation vary across the site. In the upper part of the Paluxy Formation, differences in the individual sandy and clayey units can be subtle (i.e., silty claystone compared to very fine-grained sandstone) and facies changes occur across the site (claystone may grade into very fine-grained sandstone).

Previous reports divided the Paluxy Formation at Plant 4 into upper, middle, and lower Paluxy units (Hargis + Associates 1989a, 1989b). This division was characterized as three distinct, continuous sandstone units separated by continuous beds of shale, claystone, and siltstone. Additionally, a distinct sand unit, termed the Upper Sand, was reported in the uppermost portion of the Paluxy Formation. The upper Paluxy Formation was reported to contain finer-grained sediments than the middle and lower Paluxy Formation.

Core descriptions from five boreholes drilled into the Paluxy Formation by Geotech from May to July 1991 did not substantiate the division of the Paluxy Formation described above by Hargis + Associates (1989a, 1989b), which was derived largely from drill cuttings from numerous boreholes. Because core recovery was only fair in the Paluxy Formation (many zones of very fine-grained, friable, water saturated sandstone were not recovered), geophysical logs of boreholes were evaluated to help determine if continuous clayey or shaley lithologic units separate the sandstone of the Paluxy Formation across the site. It was recognized by the Corps (1986) during their installations of Paluxy Formation monitoring wells that lithologic logs of the Paluxy Formation made from drill cuttings did not agree with the geophysical logs of the same sections of rock. Given the soft, friable character of the Paluxy Formation and its fine-grained nature, drill cuttings were often not representative of the

lithology being drilled; therefore, greater reliance can be placed on the geophysical logs to provide information on subtle lithologic changes.

Geophysical logs available for the following 11 boreholes were evaluated in a cursory nature to determine the presence of continuous clayey or shaley intervals within the Paluxy Formation: P-5U, P-9U, P-10U, P-12U, P-13M, P-15U, P-21U, P-22U, P-24EB, P-25EB, and P-26EB. The geophysical logs for the 11 boreholes are presented in Appendix L of the RI. All 11 boreholes have gamma-ray logs. In addition, resistivity and spontaneous potential logs were run in three of the boreholes, and a resistivity log was run in one of the boreholes. Only three of the geophysically-logged boreholes (P-24EB, P-25EB, and P-26EB) penetrated the entire thickness of the Paluxy Formation. One borehole (P-13U) penetrated all the way through the upper and middle portions of the Paluxy Formation. The remaining seven logged boreholes penetrated 50 feet or less into the upper portion of the Paluxy Formation.

The three deep boreholes that penetrated the entire thickness of the Paluxy Formation and were logged using borehole geophysics do not provide sufficient coverage to allow a detailed site-wide correlation of individual sandy and shaley units reported in the borehole logs.

The most extensive unit that can be mapped within the Paluxy Formation on the basis of the geophysical logs and the five Geotech core logs is a shale or silty shale bed about 3- to 5-feet thick that occurs just below a fine-grained sandstone bed five feet in thickness at the top of the Paluxy Formation. This correlation could only be made along the south edge of the Plant 4 site in boreholes P-12U, P-13U, and P-26EB (from east to west), and this relationship was verified by description of core from boreholes P-30M and P-31U in the same area. The correlation of this shale unit northward across the site in boreholes P-25EB and P-26EB is tenuous, however. At borehole P-25EB, the uppermost shale is approximately 20 feet below the top of the Paluxy Formation, and at borehole P-26EB, the first shaley unit is approximately 40 feet below the top of the formation.

Other minor shaley or silty shale units in the Paluxy Formation can be recognized in the geophysical logs, but these units do not support correlation across the site. Subtle and frequent facies changes in the fine-grained sediments of the Paluxy Formation are the principal reasons that individual shaley or clayey units in the Paluxy Formation are traceable for only hundreds of feet rather than across the site.

1.4.8 Hydrogeology

The hydrogeologic system of interest at Plant 4 includes three main units: an upper-zone ground-water system; an aquitard system composed of competent bedrock of the Goodland Limestone and Walnut Formation; and the Paluxy Aquifer, which is a source of municipal water supply for the city of White Settlement. The hydrogeology of the upper-zone ground-water system and the underlying aquitard formations are discussed in Sections 1.4.8.1 and 1.4.8.2, respectively. Hydrogeology of the Paluxy Aquifer is discussed in Section 1.4.8.3.

1.4.8.1 Upper-Zone Ground Water

Upper-zone ground water at Plant 4 occurs in unconsolidated Quaternary Period deposits and weathered Goodland Limestone, both of which overlie competent bedrock. Lithology of the upper-zone ground-water system consists primarily of silt and clay material, with silty sand and gravel deposits often present in paleochannels incised into bedrock.

The upper-zone ground-water system is underlain by competent Goodland Limestone and Walnut Formation. The Goodland Limestone is an assemblage of interbedded siltstone, claystone, and limestone. The Walnut Formation consists of highly indurated limestone and shell agglomerate. These two formations form an aquitard that restricts the flow of ground water between the upper-zone flow system and the underlying Paluxy Formation. In many areas the Goodland Limestone is located at or very near the land surface. Upper-zone ground water is essentially absent in these areas. Elsewhere, the Goodland Limestone and Walnut Formation are incised by paleochannels filled with alluvium. The Goodland Limestone is often entirely absent in these areas. Locally, such as beneath the East Parking Lot, the Walnut Formation has been eroded almost completely by a paleochannel, creating a potential for ground-water flow into the Paluxy Formation.

Detailed lithologic descriptions of the unconsolidated Quaternary Period deposit and cross sections through the upper-zone are presented in Section 1.4.7.

Upper-Zone Ground Water: Recharge and Discharge

Natural recharge to the upper-zone flow system occurs through direct infiltration of precipitation and runoff. Extensive paved areas and buildings restrict the natural infiltration of precipitation over much of Plant 4. However, precipitation does infiltrate through several large grassy areas that include portions of the flight-line area, the radar range, and Landfill Nos. 2, 3, and 4.

Additional recharge also occurs as leakage from water-supply lines, fire-fighting pipe systems, cooling-water systems, sanitary sewers, and storm sewers. Preliminary data from GD for the period January 1, 1991 through December 31, 1991, can be used to estimate losses from the combined water-supply, sanitary sewer, storm sewer and outfall (Nos. 1 and 4) systems. Data obtained from GD (General Dynamics Facility Management 1992) indicate that GD purchased 934.7 million gallons of water from the City of Fort Worth in 1991. After use, this water was then discharged to the sanitary sewer and Outfall Nos. 1 and 4. City water was also used to keep the fire-fighting system pressurized.

For 1991, Plant 4 records indicate a storm-sewer discharge of 677.6 million gallons, an Outfall No. 1 discharge of 127 million gallons, and an Outfall No. 4 discharge of 14.6 million gallons. The difference between inflow and outflow is 115.5 million gallons for 1991. This is equivalent to a leakage-induced recharge rate of 316,000 gallons per day (gpd). This value is considered to be a conservative estimate of the leakage rate because past employment and water usage have been greater than in 1991. Additionally, limited data available from earlier years suggests that losses in the past may have been greater due to temporary line breaks and/or perforations (GD Facility Management 1992).

Some losses are also expected from the cooling water system. This system consists of a 1-mile-long, 48-inch-diameter pipeline supplied with water from Lake Worth. This system delivers water under pressure to the main cooling tower and then returns it under open-channel flow conditions to the lake. The system operates at flow rates that vary between 6 and 40 million gallons per day (mgd) (GD Facility Management 1992). However, this system is not continuously monitored and leakage rates cannot be estimated.

A recharge rate of approximately 316,000 gpd over the main plant area represents a moderate flux into the upper-zone flow system. As such, losses from the pipe systems influence the direction and rate of groundwater flow and contaminant transport and contribute to the dilution of subsurface contamination.

Specifically, this localized recharge to upper-zone ground water contributes, in part, to the high hydraulic heads measured beneath Plant 4. Figure II-24 of the RI, a map of water-table elevations in the upper zone, shows two ground-water mounds in the vicinity of the main building. One mound is located at the southern portion of the Assembly Building/Parts Plant, and the second is located near the northern portion of the Assembly Building/Parts Plant. As shown in Figure II-25 of the RI, a map of the base of the upper-zone flow system, locally high areas of competent bedrock underlie the ground-water mounds. This indicates that the bedrock topography also contributes to the high water-table elevations found beneath the plant.

If the leakage from the pipe systems was reduced, water-table elevations beneath the plant would decline. This would lead to smaller hydraulic gradients, lower groundwater velocities, and lower dilution ratios for subsurface contamination. Flow directions might also change, although such changes would likely be minor as the directions of groundwater flow are strongly influenced by the topography of the competent bedrock. Given that the volume of water lost from the Plant 4 water-distribution system is typical of conventional potable water-supply systems, it is unlikely that significant reductions in the loss rate are possible, as long as the plant is in operation. Complete elimination of potable water-losses would require the excavation and replacement of tens of thousands of feet of pipe that currently underlie the main building—together with a myriad of other utilities. Nonetheless, the result of leakage reductions (and complete leakage elimination) is being examined, in terms of flow directions and gradients, via the groundwater flow model.

Discharge from the upper-zone flow system occurs primarily as seeps to Meandering Road Creek, baseflow to Farmers Branch, and discharge to the West Fork of the Trinity River. Locations of these discharge sites are shown on the regional water-table map (Figure II-26 of the RI). Discharge from the upper-zone ground water also occurs as vertical leakage into the Paluxy Aquifer. Most of the vertical leakage occurs in areas such as the axes of paleochannels where considerable portions of the Goodland Limestone and Walnut Formations are absent. Results of previous investigations indicate that one such area exists beneath the East Parking Lot. This location has been referred to as the "window area" (Figure 1-8a). The relative quantities of water discharging from the upper-zone flow system at various discharge locations are unknown.

Upper-Zone Ground Water: Hydraulics

The upper-zone flow system is bounded by the water table and the contact between unconsolidated deposits/weathered bedrock and competent bedrock. The difference in elevation between the water table and competent bedrock defines the saturated thickness. The elevation of the water table was measured at 179 upper-zone monitoring wells at Plant 4 in September 1991. One complete set of measurements was taken in September 1991. A local-scale water-table contour map, constructed from these measurements is presented in Figure II-24 of the RI. Additionally, a regional-scale water-table contour map (Figure II-26 of the RI) was constructed on the basis of upper-zone water-level measurements at Plant 4, CAFB, and surface-water elevations in the West Fork of the Trinity River.

Both Figures II-24 and II-26 of the RI show that the upper-zone flow system contains ground-water mounds at the northern and southern parts of the Assembly Building/Parts Plant. These mounds are likely a result of ground-water recharge from leaking water pipelines. As shown on Figures II-24 and II-26 of the RI, ground-water flow directions diverge from the mounds.

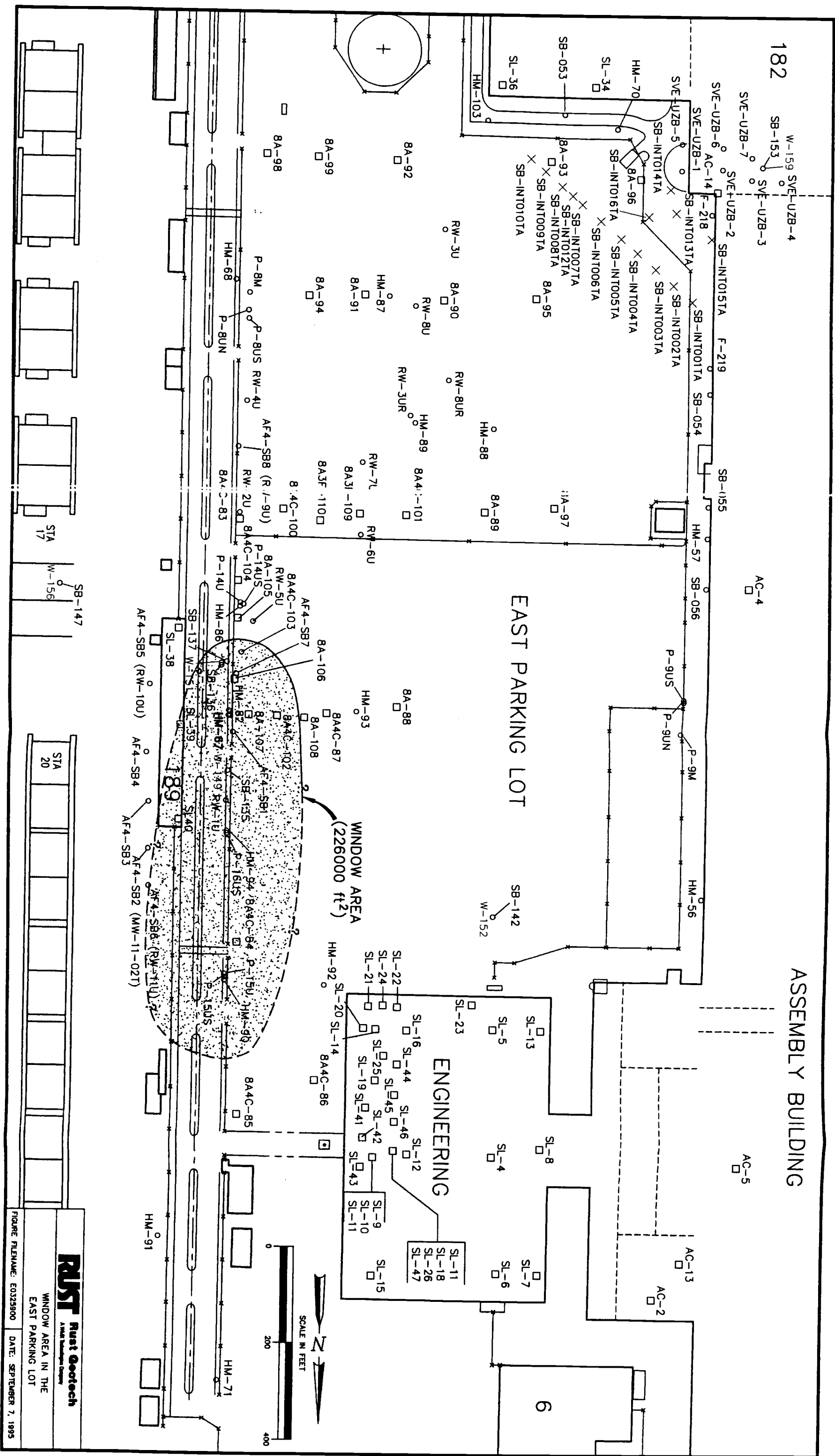


Figure 1-8A. Location of Window Area in the East Parking Lot.

Groundwater flows in three primary directions in the vicinity of Plant 4. The dominant flow direction is towards the east, originating at the south-central part of Plant 4. Secondary flow directions include the westerly flow direction originating at the west-central part of the Assembly Building/Parts Plant, and the northerly flow direction originating at the northern part of the Assembly Building/Parts Plant. Approximate hydraulic gradients (defined as the change in head along the flow path) in these three flow domains range from 0.005 to 0.01 in the easterly flow direction, 0.004 to 0.2 in the westerly flow direction, and 0.01 to 0.03 in the northerly flow direction.

The area beneath and just west of the Assembly Building is characterized by relatively flat hydraulic gradients. To show additional detail in this area, bedrock and water table contour maps plotted at 2-foot contour are provided in Figure 1-8b and Figure 1-9, respectively. These figures show that both the water-table and bedrock topography form a saddle in the vicinity of Building 14, with groundwater flow directed east and west of this saddle.

The base of the upper-zone flow system at Plant 4 is defined as the top of competent bedrock. Records of drillholes installed at Plant 4 were used to obtain elevations of the top of competent bedrock material. Figure II-25 of the RI is a contour map which illustrates the top of competent bedrock at Plant 4. Paleochannels trending northeast across the East Parking Lot, southeast across the flight lines at CAFB, and north from the northern end of the Assembly Building/Parts Plant are evident in Figure II-25 of the RI. Saturated thicknesses in the upper-zone flow system are generally greatest along the axes of these paleochannels.

Basal gravel is frequently present at the contact between competent bedrock and the upper zone. Basal gravel attains maximum thickness in the East Parking Lot area along the course of the main northeast trending paleochannel. Lithologic logs compiled by previous investigators (Hargis + Associates 1989) indicate that monitoring well HM-089, located within the paleochannel, contains 16 feet of basal gravel deposits. Basal gravel thicknesses are significantly less outside the paleochannel.

Slug tests were performed on 25 monitoring wells to obtain estimates of hydraulic conductivity in the upper zone. Some of the wells included in the slug testing program have screens that extend into weathered portions of the Goodland Limestone. It was considered appropriate to test these wells (such as W-128L, W-133L, and W-157) because the upper-zone flow system has been defined to include unconsolidated alluvium and weathered portions of the Goodland Limestone. Results of the slug tests are suitable for characterizing the hydraulic conductivity of a small cylinder of porous media that surrounds the well screen. The results of slug tests are representative of smaller volumes of porous media than are the results of conventional pumping tests. The tests were performed according to the procedures identified in the RI Work Plan. The only exception was that a different recording schedule was used to accommodate the In-Situ data loggers. Slug test analyses were based on the method of Bouwer and Rice (1976), and Bouwer (1989). The calculations associated with the slug test analysis are presented in Appendix O of the RI. Hydraulic conductivities obtained from the slug testing in the easterly flowing ground-water area are presented in Table 1-4. Estimated hydraulic conductivity values in the easterly flowing ground-water zone ranged from 1.97×10^{-2} centimeters per second (cm/s) in monitoring well W-159 to 9.76×10^{-6} cm/s in monitoring well W-157. The mean of the logarithms of the hydraulic conductivities in the easterly flowing ground-water system is 4.52×10^{-4} cm/s based on a sampled population of 13 monitoring wells. No distinct difference between hydraulic conductivity estimated for wells located within paleochannels and wells placed outside paleochannel margins was indicated on the basis of slug test results.

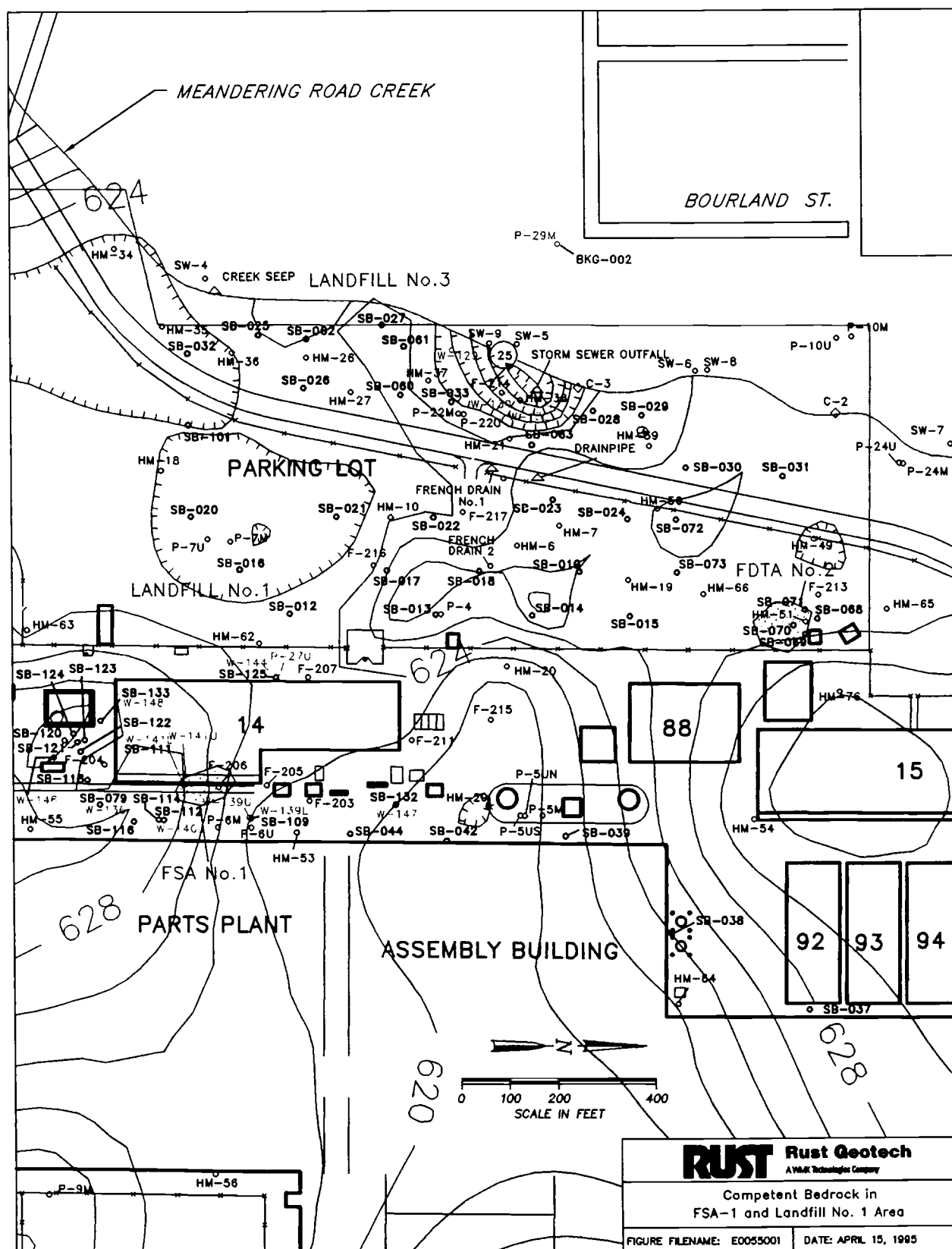


Figure 1-8B. Enlarged View Showing Elevation Contours for Competent Bedrock in FSA-1 and Landfill No. 1 Areas.

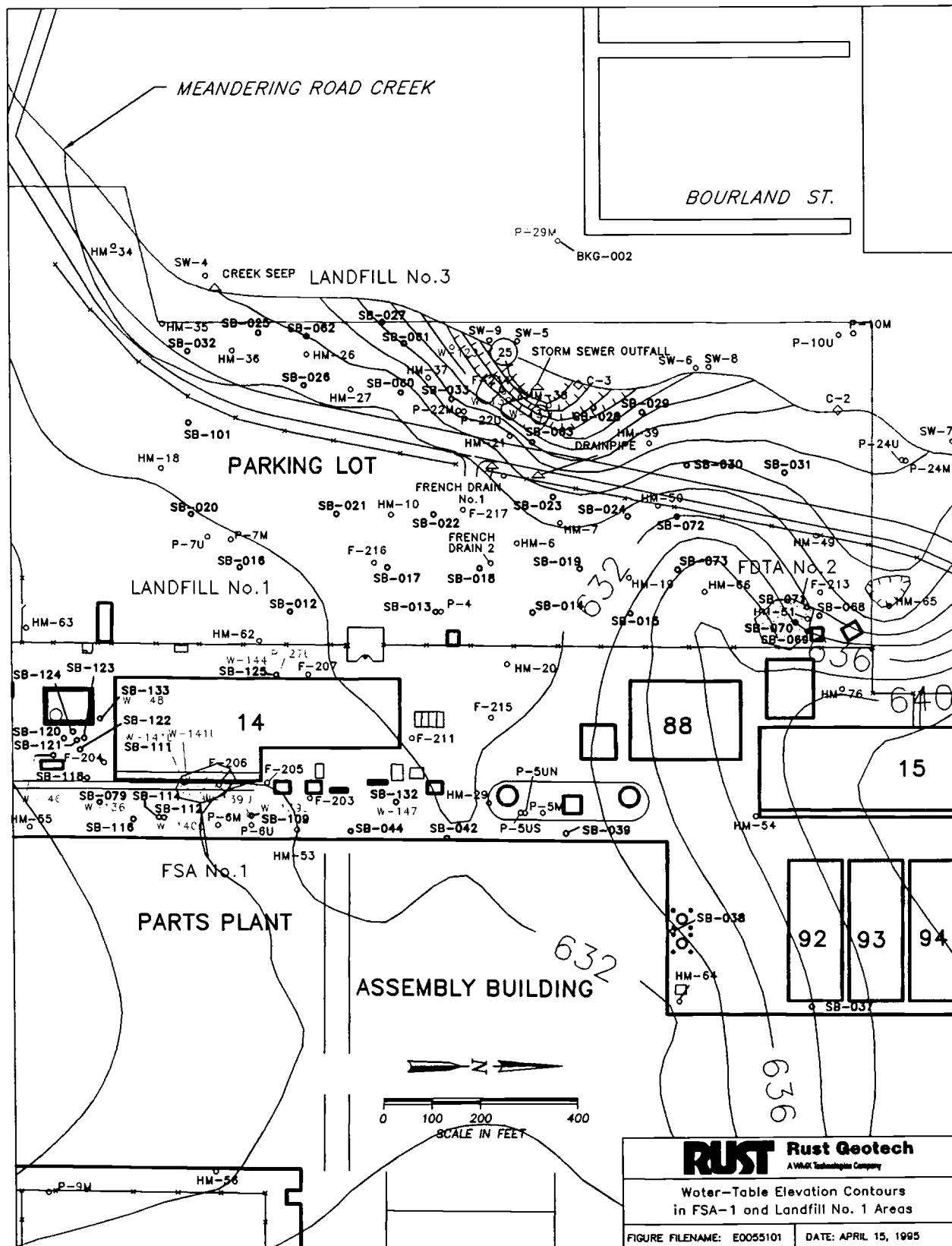


Table 1-4. Slug Test Results in Easterly Flowing Upper-Zone Groundwater 261054

Well Number(Test Number)	Hydraulic Conductivity (cm/sec)
W-128L	1.05×10^{-5}
W-131U(1)	1.01×10^{-2}
W-131U(2)	1.13×10^{-2}
W-133L(1)	1.83×10^{-3}
W-133L(2)	1.77×10^{-3}
W-149(1)	1.18×10^{-4}
W-149(2)	1.22×10^{-4}
W-151(1)	2.34×10^{-3}
W-151(2)	2.21×10^{-3}
W-153(1)	3.58×10^{-3}
W-153(2)	3.39×10^{-3}
W-156	1.85×10^{-3}
W-157	9.76×10^{-6}
W-158(1)	3.18×10^{-3}
W-158(2)	2.94×10^{-3}
W-159(1)	1.57×10^{-2}
W-159(2)	1.97×10^{-2}
W-160(1)	5.62×10^{-3}
W-160(2)	5.81×10^{-3}
HM-12(1)	5.52×10^{-3}
HM-12(2)	3.56×10^{-3}
HM-28(1)	6.90×10^{-3}
HM-28(2)	6.69×10^{-3}

Estimated hydraulic conductivity values for the westerly flowing ground-water system are presented in Table 1-5. The maximum hydraulic conductivity value in the westerly flowing ground-water area was estimated to be 1.13×10^{-1} cm/s at monitoring well W-144; the minimum value was estimated to be 7.73×10^{-5} cm/s at monitoring well W-141U. The mean of the logarithms of the estimated hydraulic conductivity values is 2.39×10^{-3} cm/s based on a sampled population of eight monitoring wells.

Estimated hydraulic conductivities for the northerly flowing ground-water area are presented in Table 1-6. The maximum hydraulic conductivity value in the northerly flowing ground-water area was estimated to be 3.00×10^{-2} cm/s at monitoring well W-143; the minimum value was estimated to be 3.75×10^{-6} cm/s at monitoring well F-212. The mean of the logarithms of the estimated hydraulic conductivity values is 5.31×10^{-4} cm/s based on a population of four monitoring wells.

Table 1-5. Slug Test Results In the Westerly Flowing Upper-Zone Groundwater

261055

Well Number(Test Number)	Hydraulic Conductivity (cm/sec)
W-136(1)	6.69×10^{-3}
W-136(2)	6.25×10^{-3}
W-140(1)	1.05×10^{-2}
W-140(2)	9.84×10^{-3}
W-140(3)	1.17×10^{-2}
W-141U	7.73×10^{-3}
W-144	1.13×10^{-1}
W-147(1)	4.03×10^{-4}
W-147(2)	2.13×10^{-4}
F-216(1)	2.06×10^{-3}
F-216(2)	2.12×10^{-3}
F-217(1)	2.32×10^{-3}
F-217(2)	2.42×10^{-3}
F-217(3)	2.45×10^{-3}
HM-27(1)	1.08×10^{-3}
HM-27(2)	1.17×10^{-3}

Table 1-6. Slug Test Results for Northerly Flowing Upper-Zone Groundwater

Well Number(Test Number)	Hydraulic Conductivity (cm/sec)
W-143(1)	3.00×10^{-2}
W-143(2)	2.76×10^{-2}
F-208(1)	2.69×10^{-4}
F-208(2)	2.54×10^{-4}
F-212	3.75×10^{-6}
HM-105(1)	2.84×10^{-3}
HM-105(2)	2.93×10^{-3}
HM-105(3)	2.70×10^{-3}

Although the number of slug tests in the different flow areas varied, the resulting estimates of hydraulic conductivity indicate that there is extreme variability in the hydraulic conductivity across the site. A mean of the logarithms of the hydraulic conductivity parameter provides an average that is skewed in the direction of lower hydraulic conductivities relative to the arithmetic mean. Given that research has shown that the hydraulic conductivity parameter is often log-normally distributed, the logarithmic approach to estimating average hydraulic conductivity is justified (Domenico and Schwartz 1990, pp. 66 - 67). Note that an average computed on the basis of the logarithms of individual conductivity values is identical to the geometric mean of the raw conductivity values (Equation 3.20, Domenico and Schwartz 1990).

Published values of hydraulic conductivities for silty sand range from 1.0×10^{-5} to 1.0×10^{-1} cm/s, and porosity values for silts and clays range from 0.20 to 0.33 (dimensionless) (deMarsily 1986, p. 36). Together with hydraulic gradient values presented earlier, the two parameters of hydraulic conductivity and porosity may be used to estimate the average linear velocity of upper-zone ground water. The average linear velocity is defined as

$$\bar{v} = \frac{v}{n} = \frac{K}{n} \frac{dh}{dl} \quad \text{Equation 1-1}$$

where: v = Darcy flux, or specific discharge ($L^3/L^2 T$)
 n = porosity (dimensionless)
 K = hydraulic conductivity (L/T)
 dh/dl = hydraulic gradient

A matrix in which Equation 1-1 is solved for each of the flow directions in the upper zone is presented in Table 1-7.

Table 1-7. Estimated Minimum and Maximum Values of Average Linear Velocity in Upper-Zone Groundwater

Flow System	Mean-of-Logs Hydraulic Conductivity (cm/s)	Assumed Porosity (dimensionless)	Hydraulic Gradient (dimensionless)	Darcy Flux (cm/s)	Average Linear Velocity (cm/s)
Easterly Flow (minimum)	1.15×10^{-5}	0.30	0.005	5.75×10^{-4}	1.92×10^{-5} (0.05 ft/d)
Easterly Flow (maximum)	1.15×10^{-5}	0.30	0.01	1.15×10^{-3}	3.83×10^{-5} (0.11 ft/d)
Westerly Flow (minimum)	2.39×10^{-5}	0.30	0.004	9.56×10^{-4}	3.19×10^{-5} (0.09 ft/d)
Westerly Flow (maximum)	2.39×10^{-5}	0.30	0.2	4.78×10^{-4}	1.59×10^{-3} (4.51 ft/d)
Northerly Flow (minimum)	5.31×10^{-4}	0.30	0.01	5.31×10^{-4}	1.77×10^{-5} (0.05 ft/d)
Northerly Flow (maximum)	5.31×10^{-4}	0.30	0.03	1.59×10^{-3}	5.31×10^{-5} (0.15 ft/d)

Except for the westerly flowing maximum value, estimated minimum and maximum average linear velocity values are relatively consistent throughout Plant 4. The maximum hydraulic gradient calculated in the westerly area was in the vicinity of Landfill No. 3. The hydraulic gradients may be steep in this area due to the head loss associated with the ground water flowing across the low hydraulic conductivity bedrock ridge that parallels Meandering Road Creek. There were no hydraulic conductivity values obtained in this area during the RI.

1.4.8.2 Goodland Limestone and Walnut Formation Aquitard

The Goodland Limestone is an assemblage of interbedded siltstone, claystone, and limestone while the Walnut Formation consists of highly indurated limestone and shell agglomerate. These two formations form an aquitard that restricts the vertical flow of ground water between the upper-zone flow system and the Paluxy Aquifer. The entire section of Walnut Formation and at least a portion of the Goodland Limestone are present within most of the Plant 4 area. In the vicinity of Plant 4, the maximum thickness of the aquitard is approximately 30 feet. However, the aquitard is thin, and in some cases nearly absent, in areas where paleochannels have incised into the Goodland Limestone and Walnut Formation. As previously discussed, the window area in which the aquitard is almost absent is located beneath the East Parking Lot. Probable weathering of the remaining veneer of Walnut Formation in this area creates a potential ground-water flow into the Paluxy Formation.

Most of the characterization activities performed during the RI focused on the Walnut Formation because the Walnut Formation comprises most of the aquitard in the vicinity of Plant 4. Vertical hydraulic conductivity of competent Walnut Formation was measured on several drilling core samples collected during the RI. Table 1-8 presents the results of the vertical hydraulic conductivity measurements. The logarithmic mean of the measured hydraulic conductivity values is 7.0×10^{-10} cm/s, based on a sampling of six cores.

Table 1-8. Results of Vertical Permeability Testing in the Competent Walnut Formation Aquitard

Sample Location	Depth of Sample	Effective Porosity (percent)	Hydraulic Conductivity (cm/s)
P-27	47'2" to 47'6"	8.6	4.2×10^{-9}
P-27	56'4" to 57'0"	8.2	5.2×10^{-10}
P-28	37'2" to 37'6"	7.2	1.2×10^{-9}
P-28	50'2" to 50' 6"	6.4	7.3×10^{-11}
P-30	38'0" to 38'6"	12	8.5×10^{-9}
P-30	52'10" to 53'4"	2.3	7.1×10^{-11}

In addition to the hydraulic conductivities discussed above, hydrographs for paired upper-zone and Paluxy Formation monitoring wells also indicate that there is relatively little flow from the upper-zone to the Paluxy Formation. Hydrographs for HM-86 and P-14US (located in the East Parking Lot window area), and W-143 and P-28U (located in the North Parking Lot) are shown in Figure 1-10 and Figure 1-11, respectively. Figure 1-10 shows two significant step-like changes in the water level in HM-86. These changes are not present in the P-14US hydrograph, indicating poor hydraulic communication. The Walnut Formation at this location is 6-feet thick. In Figure 1-11, W-143 shows two smaller increases in the upper zone water-level. Again, these trends are not present in the hydrograph for the Paluxy Formation well, P-28U.

The large differences in hydraulic head at these two pairs of wells (approximately 28 feet at HM-86/P-14US and 46 feet at W-143/P-28U) also indicates large vertical head losses, which are consistent with the presence of a low-conductivity aquitard.

At locations in the paleochannel beneath the East Parking Lot where the Walnut Formation is a minimum, the effectiveness of this aquitard is diminished and vertical flux rates will be higher. The vertical Darcy velocity and average linear velocity can be estimated using Equation 1-1 with the hydraulic gradient defined at locations of paired upper-zone and Paluxy Formation wells. Paired wells in the paleochannel-window area include P-14US/HM-86, P-15US/HM-90, and P-16US/HM-94.

Because vertical flow from the upper-zone into the Paluxy Formation is a case of flow perpendicular to layering, K in Equation 1-1 must be replaced with K_z , the equivalent vertical hydraulic conductivity (Freeze and Cherry 1979, p. 33). The expression for the equivalent vertical hydraulic conductivity is

$$K_z = \frac{d}{\sum_{i=1}^n \frac{d_i}{K_i}} \quad \text{Equation 1-2}$$

where K_z = equivalent vertical hydraulic conductivity
 d = combined thickness of heterogeneous units
 d_i = individual thickness of strata i
 K_i = hydraulic conductivity of strata i .

It is important to note that the definition of the d_i and d should be consistent with the definition of ΔL that is used in calculating the hydraulic gradient that will be used with K_z to estimate the Darcy velocity. This relationship is discussed in Appendix Q of the RI, Hydrologic Calculations, Notes, and Drawings.

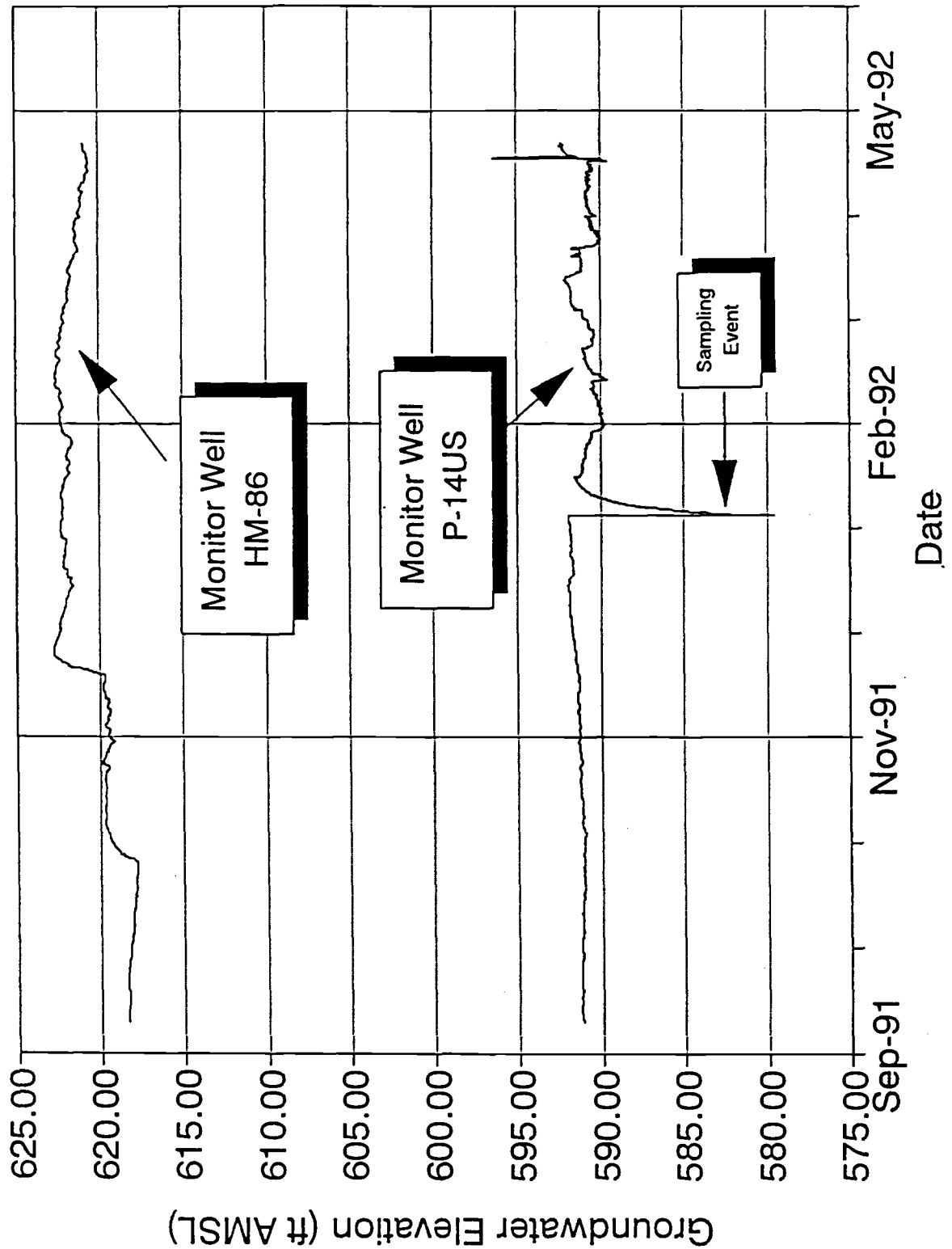


Figure 1-10. Groundwater Elevations for the Period 10 September 1991 through 19 May 1992 for Monitoring Wells HM-86 and P-14US

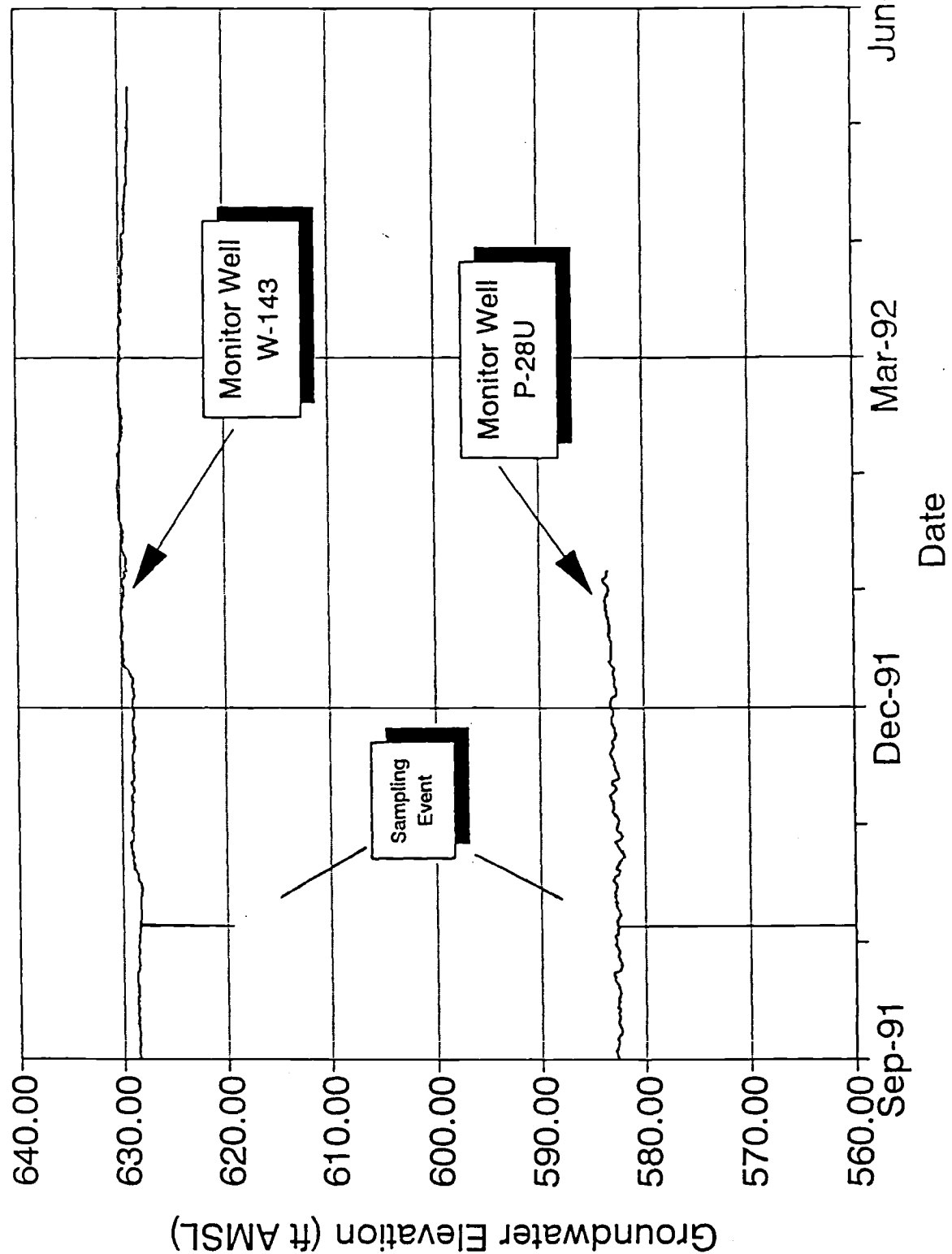


Figure 1-11. Groundwater Elevations for the Period 12 September 1991 through 19 June 1992 for Monitoring Wells W-143 and P-28U

When Equation 1-2 is used to calculate the equivalent vertical hydraulic conductivity for an interval that includes strata with very low hydraulic conductivities, d_i/K_i values for high permeability strata have a negligible contribution and are commonly ignored (see Appendix Q of the RI, Hydrologic Calculations, Notes, and Drawings).

The equivalent vertical hydraulic conductivities for the three window area well pairs are presented in Table 1-9. These equivalent vertical conductivities are then used to estimate the vertical Darcy flux and average linear vertical velocity through the Walnut Formation in the vicinity of the window area. The results are presented in Table 1-10. The complete details for these calculations are presented in Appendix Q of the RI.

Table 1-9. Estimated Equivalent Vertical Hydraulic Conductivity for Flow Through Walnut Formation

Sample Location	K_i Walnut (cm/sec)	d_i Walnut (ft)	K_i Paluxy (cm/sec)	d_i Paluxy (ft)	d (ft)	K_t (cm/s)
HM-86 and P-14US	7.0×10^{-8}	6.6	2×10^{-8}	4.75	26	7.84×10^{-8} (2.22×10^{-4} ft/d)
HM-90 and P-15US	7.0×10^{-8}	2.0	2×10^{-8}	2.5	18.0	1.17×10^{-7} (3.32×10^{-4} ft/d)
HM-94 and P-16US	7.0×10^{-8}	2.25	2×10^{-8}	3.5	19.35	9.34×10^{-8} (2.65×10^{-4} ft/d)

Table 1-10. Vertical Average Linear Velocity and Darcy Flux Through the Walnut Formation in the Window Area

Sample Location	K_t (ft/d)	Porosity (dimensionless)	Hydraulic Gradient (dimensionless)	Vertical Darcy Flux (ft/d)	Vertical Average Linear Velocity (ft/d)
HM-86 and P-14US	2.22×10^{-4}	0.074	1.1	2.39×10^{-4}	3.23×10^{-3}
HM-90 and P-15US	3.32×10^{-4}	0.074	1.2	3.86×10^{-4}	5.22×10^{-3}
HM-94 and P-16US	2.65×10^{-4}	0.074	0.3	8.57×10^{-4}	1.16×10^{-3}

In these calculations, measured K_i values were not available for the Walnut Formation in the window area. Because the Walnut Formation is thin and likely weathered in this area, K_i was assumed to be two orders of magnitude greater than the logarithmic mean K for the competent Walnut Formation, or 7×10^{-8} cm/s (see Table 1-8). For the Paluxy Formation, K_i was set equal to 2×10^{-8} cm/s, which is

the logarithmic mean of the vertical hydraulic conductivities measured for Paluxy Formation core samples (see Table 1-15).

The porosity used to calculate the average linear velocity through the Walnut Formation was 7.4 percent. This is the arithmetic average of porosity values reported for Walnut Formation core samples (see Appendix P of the RI, Vertical Hydraulic Conductivity Analysis of Walnut Formation and Paluxy Formation Core Samples via Triaxial Cell Testing).

The estimated vertical flow velocity through the Walnut Formation suggests that as long as the Walnut Formation is present, the downward flow of ground water is very limited. The primary control impeding the downward flow of ground water is the low vertical hydraulic conductivity of the competent Walnut Formation. The distribution of contamination in the Paluxy Formation over most of Plant 4 confirms that there is very little flux of upper-zone ground water flowing through the aquitard.

However, in the window area, the Paluxy Formation is significantly contaminated with TCE and its degradation products (Section 1.5.5.3). This suggests that although a remnant of the Walnut Formation may be present, it is significantly weathered. It also suggests that the degree of weathering has increased the hydraulic conductivity to the point where the aquitard is leaking appreciably in the window area. The volume of leakage through the Walnut Formation is discussed in Section 1.4.8.3.

1.4.8.3 The Paluxy Aquifer

The Paluxy Aquifer is an unconfined to semi-confined sandstone aquifer that underlies the Walnut Formation aquitard. The bottom of the Paluxy Aquifer is defined as the first occurrence of limestone beneath the Paluxy Formation. Limestone is the dominant component of the Glen Rose Formation which underlies the Paluxy Formation.

In Tarrant and Dallas Counties, the Paluxy Aquifer is widely used as a source of water for domestic, municipal, and industrial water supplies. Development of the Paluxy Aquifer began in the early 1900s, with total production in the Tarrant and Dallas County areas reaching a peak in the late 1960s (Nordstrom 1982). The decline in production since the late 1960s resulted from large declines in hydraulic head caused by heavy pumping in eastern Tarrant County and central Dallas County. The declining water levels led to the abandonment of inefficient wells (Nordstrom 1982), which were then replaced by the development of other sources, such as the Twin Mountains Aquifer. In the immediate vicinity of Plant 4, seven municipal water supply wells obtain water from the Paluxy Aquifer. These wells are owned by the city of White Settlement and are shown on Plate 2. Although complete historical production records are not available for these wells, pumpage has been relatively constant in recent years (Mike Ostrosky, city of White Settlement, telecon 1992). Average daily production rates for each of the White Settlement municipal wells are shown in Table 1-11.

As noted in Section 1.4.7, the Paluxy Aquifer has been characterized in previous site reports as a stratified aquifer consisting of three distinct flow systems separated by continuous aquitards composed of siltstone, claystone, and/or shale. Of the four references that address the hydrogeology of the Tarrant County area; Leggat 1957, Peckham and others 1963, Caughey 1977, and Nordstrom 1982. Only Leggat (1957) raises the possibility of stratified-flow characteristics within the Paluxy Aquifer. Leggat (1957) notes that the Paluxy Aquifer may be divided into upper and lower sand members and that the sand beds do not maintain constant thickness or lithology over long distances. However, specific data are not provided in support of this hypothesis.

Table 1-11. Average Daily Production for White Settlement Municipal Supply Wells Completed in the Paluxy Aquifer (data provided by City of White Settlement, October 1989)

Well Number	Average Daily Production (Gallons Per Day)	Depth of Screened Interval (Feet)	Total Depth (Feet)
WS-1	73,000	Not Available	254
WS-2	56,000	Not Available	200
WS-3	75,100	180-200	201
WS-H3	65,900	212-242	282
WS-5A	82,600	175-305	305
WS-8	68,900	175-286	286
WS-12	62,000	Not Available	195

A review of lithologic logs from previous reports (largely based on drill cuttings) and lithologic logs based on continuously-cored holes installed during the RI/FS field investigation indicates that sandstone is the most prevalent rock within the Paluxy Formation; however, the formation also contains abundant low-permeability zones comprised of interbedded shale, siltstone, and claystone. These interbedded units range in thickness from less than 1 foot to more than 10 feet. For example, in the lithologic log for well P-11M (U.S. Army Corps of Engineers 1986), the interval extending from 71 to 153 feet below ground level (bgl) was logged as "sand/sandstone" and was noted to contain nine individual "shaley zones" that ranged in thickness from 0.7 feet to 4.8 feet. The 4.8-foot shaley zone was found at 104 to 109.8 feet bgl. Thicknesses of the other shaley zones identified in the lithologic logs did not exceed three feet. Variable-thickness shale and siltstone/claystone layers separated by sandstone intervals are further documented in the lithologic logs for other wells, such as P-12M and P-13M (U.S. Army Corps of Engineers 1986) and P-27U through P-31U (see Appendix B-1 of the RI). Cross-sections prepared by previous investigators and containing many of these wells have commonly displayed these variable-thickness shale and siltstone layers as thick, continuous sequences (up to 20 feet) of low permeability rock. However, as noted above, lithologic logs for individual boreholes do not support this interpretation.

Hydrogeologic cross-sections through the Paluxy Aquifer are presented in Figures II-1 through II-10 of the RI. Water-levels shown on the cross-sections are based on September 1991 or the most recent September/October data. The location of each of the cross-sections is depicted in Plate 4. The site-scale hydrostratigraphic characteristics of the Paluxy Aquifer are shown in the three-dimensional fence-diagram presented on Plate 5. Due to the scale of the fence diagram, individual lithologic units less than 5 feet thick are not shown. Sequences within the Paluxy Formation that include shale and siltstone/claystone interbeds with thicknesses less than 5 feet are illustrated as "interbedded sandstone."

As shown by cross-sections 1 through 10 (Figures II-1 through II-10 of the RI), and as described in Section 1.4.7, individual shale and siltstone/claystone units are frequently encountered throughout the vertical extent of the Paluxy Aquifer. There appears to be a greater tendency to encounter low-permeability shale and siltstone/claystone layers in the upper portions of the Paluxy Aquifer than in the lower portions of the aquifer. In most instances, individual shale and siltstone/claystone units cannot be correlated over large distances because of the variable distribution of the units and the uncertainty associated with the lithologic logs prepared on the basis of drill cuttings.

On the basis of these observations, the Paluxy Aquifer is regarded as a single unconfined to semi-confined flow system consisting of a largely sandstone matrix with abundant layers of interbedded shale, siltstone, and claystone. This interpretation of the Paluxy Aquifer and the evaluation of Plant 4 lithologic logs prepared for the Paluxy Formation are further discussed in Chem-Nuclear Geotech (1992), "A Modification in the Former Conceptual Model of the Paluxy Aquifer Flow System."

Paluxy Aquifer Recharge and Discharge

Recharge to the Paluxy Aquifer occurs largely as infiltration of precipitation falling on the outcrop in Wise, Parker, Hood, and Tarrant Counties. Recharge also occurs as infiltration from Lake Worth and Eagle Mountain Lake, both of which lie at least partially within the boundary of the outcrop. Additional minor amounts of recharge also occur as infiltration from streams that cross the outcrop. In the immediate vicinity of Plant 4, it is evident that small amounts of recharge are also derived from leakage of upper-zone ground water through the window area (where the Walnut Formation has been severely eroded) and leakage of surface water through the lower reaches of Meandering Road Creek. In both of these areas, most, if not all, of the Walnut Formation has been eroded, reducing the capacity of this aquitard to impede the vertically downward flow of upper-zone ground water and surface water.

Evidence of recharge entering the Paluxy Aquifer in these areas is provided by the hydraulic head data from "US," "U," and "M" series wells located within these potential recharge areas. In the window area, the uppermost Paluxy wells are those with a "US" designation. The "U" designation indicates those wells completed in the next lower portion of the Paluxy Aquifer. As shown in Appendix D-1 of the RI, the fence diagram (Plate 5), and Figures II-1, II-2, and II-8 of the RI, "US" wells located in the vicinity of the window area (P-8, P-9, P-14, and P-15) have water levels several feet higher than the paired "U" wells at these locations. This indicates that downward flow occurs within the Paluxy Aquifer at these locations. This downward flow most likely originates as recharge transmitted through the eroded portion of the Walnut Formation. This same characteristic is observed in the "U" and "M" wells at P-10 and P-24. These two well pairs are located in the vicinity of lower Meandering Road Creek, where erosion has also removed much of the Walnut Formation bedrock.

Using the Darcy flux calculation from Section 1.4.8.2, it is possible to estimate the vertical flux rate through the Walnut Formation in the window area. The volumetric flux is given by $Q = V \cdot A$, where V is the Darcy flux through the Walnut Formation given in Section 1.4.8.2, and A is the area through which flow occurs. As noted in the lithologic log for monitoring well HM-94 (Hargis + Associates 1985a), the Walnut Formation is 1.5 feet thick at this location. Similar thicknesses are reported for the Walnut Formation at nearby wells P-15 and P-16 (located approximately 250 feet apart). Assuming that flow occurs through an area encompassed by a 250-foot-radius circle where

the Walnut Formation is approximately 1.5 to 2.5 feet thick, an upper limit on the estimate of recharge flux into the Paluxy Aquifer would be:

$$(2.4 \times 10^{-4} \text{ ft/d}) 226,000 \text{ ft}^2 = 50 \text{ ft}^3/\text{d}.$$

This calculation is based on the average of the Darcy flux rates at P-15 and P-16 (Table 1-9) and the assumption that the Walnut Formation is weathered in the window area. If the Walnut Formation limestone found in the window area remains indurated and competent, the recharge flux through the thinnest portion of the formation could be as low as 0.5 ft³/d. Smaller fluxes can be expected elsewhere in the East Parking Lot paleochannel where Walnut Formation thicknesses exceed the 1.5 to 2.5 feet observed in the Window Area.

Further understanding of the window area vertical flux will be obtained during calibration of the site-scale flow model. During this phase, vertical flux parameters will be adjusted in order to match calibration targets in the window area. Numerical simulations will then provide improved estimates of the vertical flux in the window area.

Although no direct measurements of infiltration derived from precipitation have been made or reported in the literature, a qualitative estimate can be developed by considering several factors. Nordstrom (1982) notes that average annual precipitation on the Paluxy Formation outcrop is 31 inches. However, only a small fraction of the 31 inches becomes recharge, as most is lost to runoff and evapotranspiration. Leggat (1957) reports that annual runoff accounts for 2.5 to 4 inches per year, and evapotranspiration during the growing season accounts for another 67 percent of annual precipitation, or 21 inches. This leaves between 6 and 7.5 inches available for recharge and evapotranspiration during spring, fall, and winter. Assuming off-season evapotranspiration consumes 2 to 5 inches of this remainder, maximum recharge rates are likely to be in the range of 1 to 5 inches per year. Based on a simple mass balance calculation for the Trinity-group aquifer system, Nordstrom estimated that effective recharge was approximately 5 percent, or 1.5 inches per year. Recharge estimates of 1 to 5 inches per year are supported by preliminary results of a numerical simulation of the Paluxy Aquifer flow system. This model encompasses western Tarrant County and Eastern Parker County (Figure II-30 of the RI) and is based on an assumed recharge rate of 2 inches per year over the outcrop.

Discharge from the Paluxy Aquifer is largely due to pumping from numerous water-supply wells throughout Tarrant, Dallas, and surrounding counties. It is likely that some discharge also occurs as ground-water evapotranspiration from the outcrop area and baseflow to streams, Lake Worth, and Eagle Mountain Lake.

Maximum production from Paluxy Aquifer wells was 13,000 acre-feet per year in both 1963 and 1969 (Nordstrom 1982). Production for 1976, the last year for which data are published, was 9,600 acre-feet.

Paluxy Aquifer: Hydraulics

Regional literature classifies the Paluxy Aquifer as an unconfined flow system in the Tarrant County area. As shown in the cross-sections presented in Figures II-1 through II-10 of the RI, the high frequency of interbedded shale and siltstone/claystone units can be expected to cause the aquifer to behave in a semi-confined manner in the immediate vicinity of Plant 4.

Maps of Paluxy Aquifer water-level elevations in the Parker and Tarrant County areas surrounding Plant 4 are shown in the RI's Figure II-28 for the year 1955, Figure II-29 of the RI for the year 1989, and Figure II-31 of the RI for the year 1976. These maps show that the regional flow direction in the Paluxy Formation has been and remains nearly due east. The maps for 1955 and 1976 were reproduced from Leggat (1982). The map for 1989 was reproduced from an unpublished map on file with the Texas Water Commission. Comparison of Figures II-28 and II-31 of the RI show that hydraulic heads have remained relatively constant in the eastern portion of Parker County. This is indicative of near-steady state flow conditions in the portion of the Paluxy Aquifer that lies west of the Tarrant-Parker county line.

In central Tarrant County, near the eastern edge of Figures II-28 and II-31 of the RI, water-table elevations declined between 1955 and 1976 by nearly 100 feet in some areas. This large drawdown was due mainly to a large cone of depression created by heavy pumping in the vicinity of the cities of Euless (in eastern Tarrant County) and Dallas (in central Dallas County). This cone of depression is easily recognized in Figure 31 of Leggat (1982).

Comparison of the contours shown in the 1976 and 1989 maps suggests that water-table elevations increased over this 13 year period. However, this apparent increase is an artifact of the relatively small number of data points used to prepare the 1989 map. Comparison of individual data points common to both maps indicates that elevations have remained relatively constant or declined only slightly within the area encompassed by Figure II-29 of the RI. Leggat (1982) speculated that water levels would increase following the decline in production from the Paluxy Aquifer in the late 1960s. The data have not confirmed this prediction, but water levels have remained relatively constant over much of the area of interest (Figures II-29 and II-31 of the RI). This observation is consistent with Plant 4 water-level data that includes three sets of continuous water-level monitoring data (Figure 1-10, Figure 1-11, and Figure 1-12), and multiple sets of synoptic water-level measurement data (Appendix D-1 of the RI).

It is important to note that the water-level elevation maps presented in Figures II-28, II-29, and II-31 of the RI are based on relatively coarse distributions of data points that do not include data from the immediate vicinity of Plant 4. Consequently, these maps do not illustrate the locally unique aspects of the Paluxy Formation flow system that may be related to the White Settlement municipal supply wells.

To assess the local nature of the Paluxy Aquifer ground-water flow in the vicinity of Plant 4, a fourth contour map was prepared using water levels obtained from (1) field measurements in Plant 4 monitoring wells, (2) published reports of water-level data from nearby supply-wells (Nordstrom 1982), (3) unpublished reports of supply-well water-level data (Texas Water Commission, Ground Water Data System), and (4) a regional-scale numerical simulation of ground-water flow in the Paluxy Aquifer. The resulting site-scale contour map is shown in Figure 1-13. The domain and finite

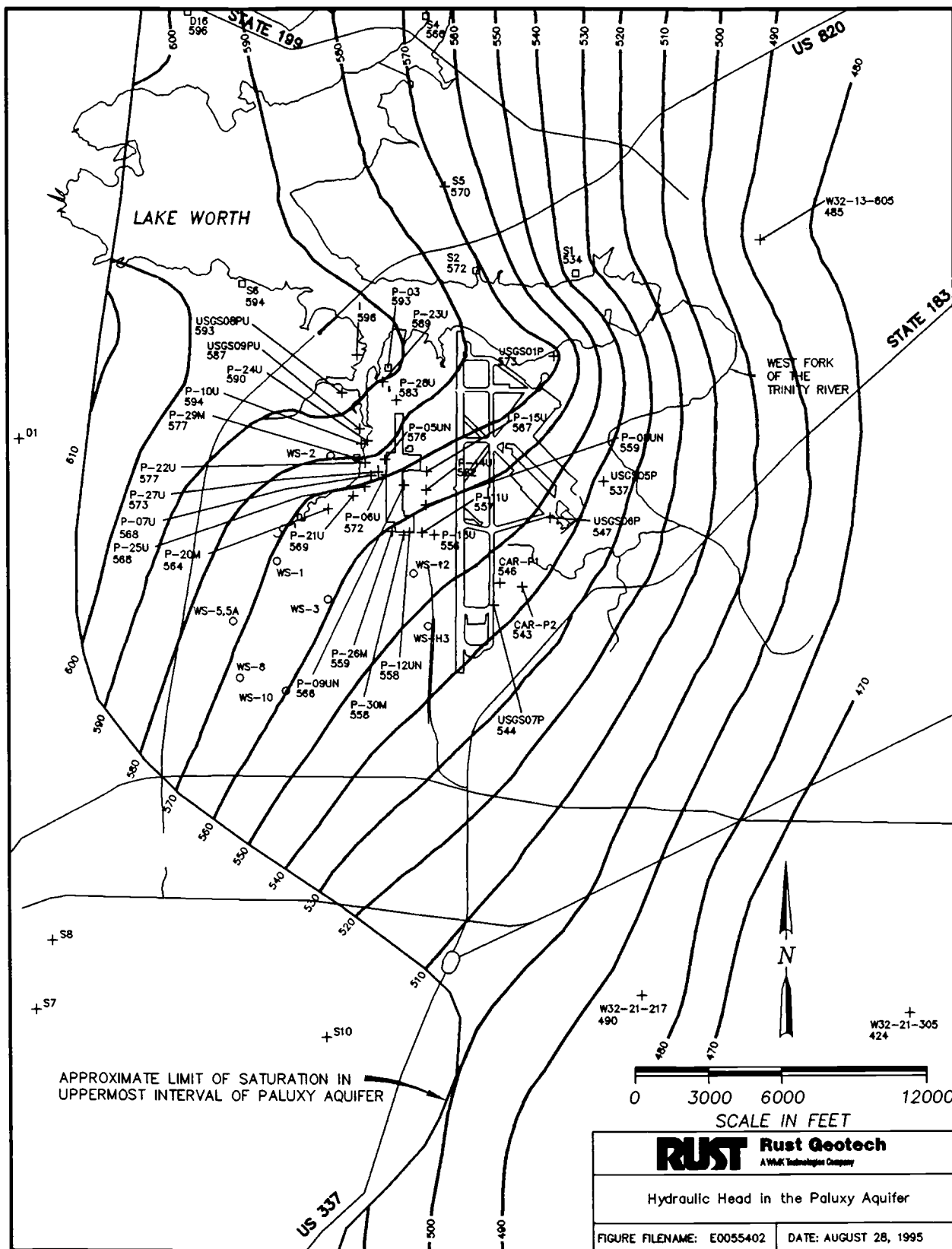


Figure 1-12. Site-Scale Map of Water Table Elevation in the Paluxy Aquifer in the Immediate Vicinity of Air Force Plant 4.

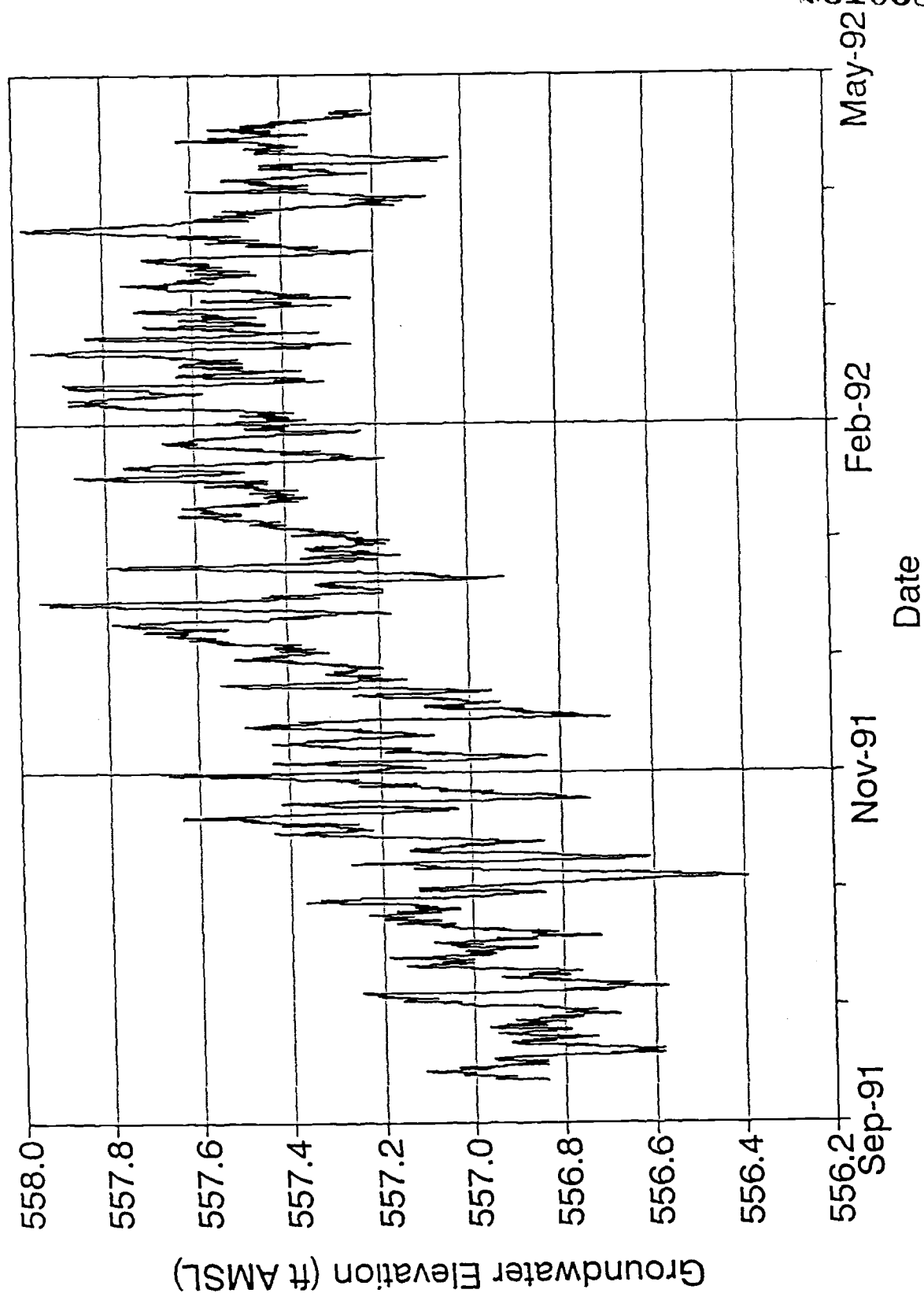


Figure 1-13. Groundwater Elevations at Monitoring Well P-11U from
12 September 1991 through 19 May 1992

difference grid for the regional-scale model are shown in Figure II-30 of the RI. The outer limits of the model domain correspond to the limits of the contour maps shown in Figures II-28, II-29, and II-31 of the RI.

For most of the White Settlement municipal wells, three water levels were available over the 37 year period from 1955 to 1991. Typically, each well had one value for the 1950s (or 1960s), one value for the 1970s, and one value for 1991. However, these data were not included in the site-scale contour map (Figure 1-13) for two reasons. First, water-level data for municipal wells WS-2 and WS-H3 indicated that significant declines had occurred during the 1980s, and that these declines have nearly dewatered the aquifer. Continuous declines in water levels are not consistent with regional and site data that indicate steady-state conditions, as described earlier. Additionally, it seems unlikely that the Paluxy Aquifer could be dewatered by wells pumping only 39 and 45 gallons per minute (gpm).

Secondly, White Settlement well data were not used because 1991 water levels for two of the wells indicated increasing aquifer head over recent years. In the absence of a regional increase in water levels caused by a major change in pumping withdrawals, increasing water levels are not possible for two isolated wells that have been in continuous, steady operation.

The problems associated with the White Settlement well data indicate that at least some of these water-levels may not reflect actual aquifer conditions. Additional data for the 1980s might have resolved some of these questions. Because the 1980s data could not be obtained from the city of White Settlement, the impact of drawdown caused by the White Settlement wells was accounted for by using the simulation results from the ground-water flow model.

The model results and field data presented in Figure 1-13 show that significant drawdown has occurred in response to pumping from WS-2, WS-H3, and WS-12. This drawdown, combined with the apparent effects of recharge from Lake Worth, produce flow directions that range from southerly on the west side of the plant to southeasterly in the flightline area. It is clear from Figure 3.8.3-2 that wells WS-12 and WS-H3 receive Paluxy Formation groundwater that has flowed beneath Plant 4.

Saturated thicknesses in the Paluxy Aquifer are shown in Table 1-12. With the exception of the relatively small value at P-1, these data are consistent with the regional literature (Leggat 1957, Peckham and others 1963, and Nordstrom 1982), which reports that the Paluxy Aquifer maintains a relatively uniform thickness in the Tarrant County area, except where significant dewatering has occurred.

To determine the horizontal hydraulic conductivity (K_h) of the Paluxy Aquifer, slug tests were conducted on the four new Paluxy Formation monitoring wells. Hydraulic conductivities estimated from the slug tests are shown in Table 1-13. Vertical hydraulic conductivity (K_z) was estimated via triaxial cell tests on core samples obtained from the monitoring-well boreholes.

As shown in Table 1-13, the K_h estimates are relatively uniform for the four wells. The minimum value obtained at P-28U is not surprising since the upper portion of the Paluxy Aquifer is typically characterized by a high proportion of low permeability rock (see Section 1.4.7). However, the difference between the K_h values for "U" and "M" wells is not as great as expected. This may be explained in part by the fact that the well-screens for the two "U" wells were placed at depths containing relatively clean sandstone (see Appendix D-1 of the RI).

Table 1-12. Saturated Thickness of the Paluxy Formation at Locations of Fully Penetrating Monitor Wells

Well Number	Saturated Thickness (Feet)
P-1	119
P-3	168
P-4	148
P-24	155
P-25	145
P-26	143

Table 1-13. Hydraulic Conductivities (K_h) Estimated from Slug Tests

Well Number	K_h (cm/sec)
P-27U	3.84E-03
P-28U	6.63E-04
P-29M	1.83E-03
P-30M	2.73E-03

Additional K_h estimates from pumping tests conducted by Hargis + Associates (1985a) range from 4.7×10^{-3} to 2.7×10^{-2} cm/sec (Table 1-14). Values from both the Hargis + Associates pumping tests and the Geotech slug tests are consistent with ranges published in the regional hydrogeologic literature.

The hydraulic conductivity corresponding to the logarithmic mean of the slug-test and pumping-test K_h estimates is 6.4×10^{-3} cm/sec (or 18.3 ft/d). Using 1 ft/340 ft to 1 ft/100 ft as a range for the average hydraulic gradient in the Paluxy Formation (Figure 3.8.2-1) and 0.27 as the average effective porosity (Advanced Terra Testing 1991; provided in Appendix P), the average linear velocity [$\bar{v} = K \times dh/dl \times (1/n)$] in the Paluxy Aquifer is likely to be within the range of 0.20 ft/d to 0.68 ft/d. In areas of clean, high-permeability sandstone or large hydraulic gradients, such as near supply wells, average linear velocities will be considerably higher than these estimates.

Vertical hydraulic conductivity estimates (K_z) were obtained from laboratory triaxial cell tests on core samples from wells P-27U, P-28U, and P-30M (Appendix P of the RI). The results, shown in Table 1-15, indicate that K_z is highly variable within the Paluxy Aquifer. Variable K_z estimates were expected, given the interbedded nature of the Paluxy Formation and the fact that the cores were taken from intervals characterized by varied lithologies (Table 1-15).

Table 1-14. Hydraulic Conductivities in the Paluxy Formation Aquifer Estimated from Pumping Tests (Hargis + Associates 1985a)

Pumping Well	Observation Well	Saturated Thickness (Screen Length) (Feet)	Transmissivity		Average Hydraulic Conductivity	
			Drawdown ft/day	Recovery ft/day	ft/day	cm/sec
P-1	P-1	60	4011	3209	60.2	2.1×10^{-2}
P-2	P-2	40	1872	2273	51.8	1.8×10^{-2}
P-3	P-3	70	NA	1110	15.8	5.6×10^{-3}
P-4	P-4	50	1016	749	17.6	6.2×10^{-3}
P-5M	P-6M	40	2139	1110	40.6	1.4×10^{-2}
P-6M	P-5M	50	3209	989	42.0	1.5×10^{-2}
P-7M	P-7M	40	NA	535	13.4	4.7×10^{-3}
P-8M	P-9M	60	4278	4947	76.9	2.7×10^{-2}
P-9M	P-9M	40	936	1110	25.6	9.0×10^{-3}
P-10M	P-10M	30	334	575	15.2	5.4×10^{-3}

NA Not Available

Table 1-15. Vertical Hydraulic Conductivity, K_z , Determined from Laboratory Triaxial Cell Tests on Core Samples Obtained from the Paluxy Formation Aquifer.

Well Number	K_z (cm/sec)	Lithology of Core Sample
P-27U	3.3E-10	Siltstone with some clay
P-28U	3.1E-09	Calcareous, fine-grain sand
P-30M	1.2E-05	Quartzose sandstone

The variability in K_z illustrated by Table 1-15 is also evident in the results of pumping tests conducted by Hargis + Associates (1985a). During a pumping test at the P-7 well pair, water was pumped from P-7M while water levels were monitored in both P-7M and P-7U. The water level in P-7U, screened above P-7M, showed a rapid and significant decline in response to the pumping from P-7M. This result indicates that the vertical interval between P-7U and P-7M has a relatively high K_z , even though the lithologic log for P-7M reports a 5-foot-thick sandy claystone between the screens of the two wells. In similar tests at other well pairs, little or no response was observed in upper well completions during pumping of the lower wells, indicating low K_z values between the monitoring points. These results provide further indication of the variability of K_z in the Paluxy Aquifer. Further understanding of this variability will be gained during the site-scale flow modeling.

1.5 Nature and Extent of Contamination

1.5.1 Introduction

This section summarizes sampling and analysis activities that were conducted to characterize the extent and nature of soil, surface water, tissue, and groundwater contamination associated with the manufacturing operations at Plant 4. Preliminary Assessment/Site Inspection (PA/SI) investigations were conducted at the Assembly Building/Parts Plant and at the underground storage tank sites, and RI studies were conducted at the remaining sites in accordance with the *Final Sampling and Analysis Plan for the Preliminary Assessment/Site Inspection and Remedial Investigations/Feasibility Studies at Air Force Plant No. 4* (UNC Geotech, Inc. 1990).

Results of sampling and analyses and discussions for the various media are presented in each subsection in the following order: Section 1.5.2, "Field Quality Control for Soil and Water Samples;" Section 1.5.3, "Source Areas and Soil Contamination;" Section 1.5.4, "Sediment Contamination;" Section 1.5.5, "Groundwater Contamination;" Section 1.5.6, "Surface Water Contamination;" Section 1.5.7, "Ecological Contamination;" and Section 1.5.8, "Air Contamination."

1.5.2 Field Quality Control For Soil and Water Samples

Field quality control was implemented to ensure that the samples collected for laboratory analyses adequately represented the environmental media and that the quality of resulting data was maintained. Sample collection, identification, custody, and shipments were performed in accordance with the *Plant 4 Final Sampling and Analysis Plan* (SAP). Field quality control checks employed for the soils investigation consisted of analyses of trip and field blanks, field duplicates, and liquids used to decontaminate and rinse sampling equipment as specified in the SAP. Results of the field quality control analyses for the soil and water samples are presented in Appendices E and F of the RI, respectively. (See appendices for definitions of qualifiers that follow concentration values.)

1.5.2.1 Quality Control Samples

Trip Blanks

Trip blanks consist of samples of laboratory deionized water that accompany the environmental samples through the entire sampling process. Trip blanks were analyzed for Volatile Organic Compounds (VOCs) to detect potential contamination during shipment.

For the soil sampling, approximately two trip blanks were prepared for every sampling trip (10 days) at the beginning of the campaign. The frequency was decreased to one trip blank for every sampling trip toward the end of the sampling campaign. A total of 11 trip blanks were submitted with the environmental soil samples. Acetone was detected at relatively low concentrations (5BJ, 11, and 10 µg/L) in three trip blanks associated with the soil sampling. Toluene and methylene chloride were also detected at a relatively low concentration of 0.6J and 4J µg/L, respectively. No other VOCs were detected. Appendix E of the RI summarizes the analytical results for the trip blanks associated with the soil samples.

A total of 18 trip blanks were prepared and submitted with each sample shipment during the water sampling campaign. 2-Butanone, acetone, trichloroethylene (TCE), and methylene chloride were each detected once at a relatively low concentration of 18, 12, 3, and 10 $\mu\text{g/L}$, respectively. No other VOCs were detected in any of the samples.

Field Blanks

Field blanks are samples of deionized water that are prepared at the monitoring well sampling site and are used to detect accidental or incidental contamination. These samples remain with the field samples through the entire sampling and shipping process. Two field blanks were collected during the groundwater monitoring campaign and analyzed for VOCs. No VOCs were detected in any of the field blanks.

Appendix F of the RI summarizes the analytical results for the trip and field blanks associated with the water sampling.

Decontamination Liquids and Equipment Blanks

One sample of tap water was collected directly from the domestic water supply source and analyzed for VOCs, total petroleum hydrocarbons (TPH), and inorganics. This water source was used as the first rinse in the decontamination process. The analytical results indicate the presence of dibromochloromethane (5 $\mu\text{g/L}$), chloroform (7 $\mu\text{g/L}$), and bromodichloromethane (9 $\mu\text{g/L}$). TPH is less than the detection limit (0.5 mg/L). No other VOCs were detected. Copper (14.7B $\mu\text{g/L}$), lead (2.2B $\mu\text{g/L}$), and zinc (98.4 $\mu\text{g/L}$) are the only inorganics detected. These results are presented in both Appendices E and F of the RI.

Methanol used in the decontamination procedure was submitted for volatile organic analyses. 2-Butanone was detected at a concentration of 10,000 $\mu\text{g/L}$. No other VOCs were detected. Results of the VOC analyses on the methanol sample are presented in Appendices E and F of the RI.

Equipment blanks are samples collected after the last rinse with deionized water is passed over the sampling apparatus after cleaning. This sample is used to check for residual contamination. Appendices E and F of the RI summarize the results for all the equipment blank analyses associated with the soil and water samples, respectively.

Tabulated in Appendix E of the RI are the VOCs and semi-VOCs that were detected in the equipment blanks collected during the soil sampling activities. The VOCs detected are acetone, 2-butanone, TCE, methylene chloride, chloroform, and toluene. Semi-VOCs detected are pyrene, nitrobenzene, and bis(2-ethylhexyl)phthalate. Bis(2-ethylhexyl) phthalate, acetone, and nitrobenzene were also detected in the laboratory method blank for some of these samples. In the case of nitrobenzene, all the reported values above the detection limit in the soil equipment blanks and the soil samples are a result of the laboratory inadvertently spiking the samples with the incorrect surrogate solution; nitrobenzene was used instead of the deuterated nitrobenzene-D5. This error resulted in nitrobenzene being reported in the equipment blanks at concentrations ranging from 45 to 60 $\mu\text{g/L}$ and in soil samples at a level of approximately 1,700 $\mu\text{g/kg}$. The first 93 samples analyzed are affected by this error.

Equipment blanks were analyzed for TPH and oil and grease with neither detected (less than 0.5 mg/L) in any of the samples. Eight priority-pollutant metals were detected in numerous equipment blank samples. Most of the results (See Appendix E of the RI) are reported above the Instrument Detection Limit (IDL) but less than the Contract Required Detection Limit (CRDL).

Tabulated in Appendix F of the RI are the VOCs and inorganic analytes detected in the equipment blanks associated with the water samples. Acetone was detected in three samples at relatively low concentrations of 11J, 6J, and 13 $\mu\text{g/L}$. TCE was also detected in two samples at relatively low concentrations of 11 and 5J $\mu\text{g/L}$. Chloroform and 2-butanone were each detected once at 14 and 9BJ $\mu\text{g/L}$, respectively. No other VOCs were detected. Cadmium, copper, lead, and zinc are the only inorganic constituents detected in the water sample equipment blanks. In most cases, the results are reported above the IDL but less than the CRDL.

Equipment blanks associated with the water sampling were also analyzed for semi-VOCs, TPH, and oil and grease; none were detected in any of the samples.

Field Duplicate

A field duplicate (split) sample was used to evaluate the overall precision of the sampling process and to a lesser extent the laboratory analytical variability. Approximately 10 percent of the environmental samples were collected as field duplicates. Duplicate soil and water sample results are summarized in Appendices E and F of the RI, respectively.

The precision is evaluated by the relative standard deviation (RSD), calculated as the standard deviation divided by the mean, then multiplied by 100, for each paired sample having values greater than the Contract Required Quantitation Limit (CRQL) (for organics) or the CRDL (for inorganics). Only those instances where both paired values are greater than the CRQL or CRDL are considered appropriate for calculating the RSD because the CRQL or CRDL is the minimum concentration that is quantitatively meaningful.

An RSD of 30 percent or less is generally considered an acceptable level of precision for field duplicate water samples. Duplicate soil samples are collected after the homogenization step at the site and typically have higher variability than water samples because of the difficulty in collecting an identical homogenized soil sample. An RSD of 50 percent for a soil sample is not unexpected.

The average RSDs for soil samples, summarized in Table 1-16, indicate acceptable precision for each type of analysis. In all cases, except for oil and grease, the average RSD is less than 30 percent. The average RSD for oil and grease is less than 50 percent.

The average RSDs for water samples, summarized in Table 1-17, indicate acceptable precision for VOCs and priority pollutant metals. The average RSD for these analyses is less than 30 percent. RSDs could not be calculated for the remaining analytes because all results between the paired samples are less than the CRQL.

Table 1-16. Average RSD for Soil Sample Analyses Above the CRQL/CRDL

Analysis	Number of Sample Pairs	Average RSD (%)
Semi-VOCs	10	17.4
VOCs	28	29.2
Oil and Grease	4	38.4
Total Petroleum Hydrocarbons	6	24.6
Priority-Pollutant Metals	130	16.6

In addition to the field duplicate samples internal to the investigation, 20 samples were also split with EPA Region VI including seven soil samples, two sediment samples, two surface water samples, and nine groundwater samples. These split samples were typically analyzed for Target Compound List (TCL) Volatile Organic Acid (VOAs), TCL Base Neutral Acid (BNAs), and Target Analyte List (TAL) inorganics. Sample results reported by EPA Region VI are consistent with those reported by Geotech for all but four analytes in three samples. Appendix S of the RI contains the data reported by EPA Region VI along with a discussion of the data presented and the discrepancies noted.

Table 1-17. Average RSD for Water Sample Analyses Above the CRQL/CRDL

Analysis	Number of Sample Pairs	Average RSD (%)
Semi-VOCs	NA	NA
VOCs	28	11.9
Oil and Grease	NA	NA
Total Petroleum Hydrocarbons	NA	NA
Priority-Pollutant Metals	35	15.4

1.5.3 Source Areas and Soil Contamination

In some cases, several sites with associated contamination were combined into the same subsection. Each subsection contains a discussion of previous investigations and if applicable, previous data have been used to assist in the interpretation of the Geotech results. For ease of presentation and interpretation of results, the minimum concentration, maximum concentration, and the number of soil samples analyzed are tabulated in each subsection. Soil samples were analyzed for VOCs, semi-VOCs, TPH, and inorganic constituents.

The number of sample analyses above the CRQL are also tabulated for VOC, TPH, and semi-VOC results. The CRQL represents the minimum concentration at which a measurement becomes quantitatively meaningful. Values above this limit are typically indicators of environmental contamination.

Similarly for the inorganic results, the number of sample analyses above the upper limit of natural background concentration of metals in soils from the western United States are tabulated in each subsection. The range in natural background concentrations in the western United States for the 12 priority-pollutant metals are presented in Table 1-18. At two Plant 4 locations soil samples were collected in areas that were not suspected to be associated with contamination. These results are presented in Table 1-18 for comparison with the range in natural background for the western United States. Also summarized in Table 1-18 are the number of samples analyzed at Plant 4 that exceed the upper limit of natural background for the western United States. Values greater than the upper limit of natural background are typically indicators of environmental contamination and are discussed separately in subsections 1.5.3.1 to 1.5.3.16.

1.5.3.1 Assembly Building/Parts Plant

Summary of Investigations

Previous Investigations: Past spills of TCE have reportedly occurred within the Chemical Process Facility (Building 181) of the Assembly Building/Parts Plant. Trenches, sumps, floor drains, and buried pipelines are also present throughout the manufacturing facility. These are all potential source areas for soil contamination resulting from spills and leaks. Widespread TCE contamination in the groundwater was identified by previous investigators in the area east of the Assembly Building/Parts Plant; however, chemical analyses of soil samples in this area is limited.

Seventy-eight test holes were drilled at Plant 4 between 1942 and 1967 to investigate the subsurface conditions of foundations for proposed building sites. In 1942 and 1952, the Austin Company drilled test holes AC-1 to AC-18 and in 1964 and 1967 Southwestern Laboratories Inc. drilled test holes SL-1 to SL-47. GD drilled test holes GDC-1 to GDC-13 in 1982. The 78 test holes range in depth from 10 to 113 feet with many of the test holes located in the area of the Assembly Building/Parts Plant and in the East Parking Lot area. These test holes provided soil types and depth to the underlying Walnut Formation.

Numerous upper zone monitoring wells (HM-31, -47, -48, -52, -53, -55 thru -59, -64, -69, -70) and Paluxy monitoring wells (P-5, -6, -9) were installed by Hargis + Associates (1985a) to define the lateral and vertical extent of groundwater contamination in the area surrounding the Assembly Building/Parts Plant (Plate 3). Soil sampling and chemical analysis were not reported for the above monitoring well borings.

The U.S. Army Corps of Engineers drilled Paluxy monitoring well P-12 along the south side of General Warehouse Building No. 188 (Plate 3). Analysis of groundwater samples detected the presence of 1,1,1-trichloroethane (TCA) and oil and grease. No soil contamination was reported.

Two monitoring wells, F-218 and F-219 (Plate 1), were installed by Intellus at the south end of the east side of the Assembly Building. These wells were drilled to confirm the presence of Chrome Pit No. 1.

Table 1-18. Concentration Range of Priority Pollutant Metals in Background Soils of the Western United States

Metal	Measured Concentration Range at Plant 4 Background Locations (mg/kg)^a	Range in Background Soils of Western USA (mg/kg)^b	Measured Concentration Range at Plant 4 (mg/kg)	Number of Samples Analyzed at Plant 4	Number of Samples Above Upper Background Range for Western USA^c
Antimony	(12.3) ^d	0.1 - 2.2	(8.0) - 77.5	407	14
Arsenic	3 - 4.4	1.4 - 21.6	(0.6) - 21.7	407	1
Beryllium	0.56B - 0.84B ^e	0.1 - 3.6	(0.21) - 1.5	407	0
Cadmium	(1.1) - 2.4	NA ^f - 2.8 ^g	(0.8) - 594	407	29
Chromium	10.6 - 16.2	8.5 - 196.6	1.5B - 3,170	407	9
Copper	3.1B - 6.9	4.9 - 90.0	1.3B - 8,060	407	19
Lead	10.9 - 18.5	5.2 - 55.1	0.87 - 10,400	407	37
Nickel	11.2 - 19.8	3.4 - 66.2	(3.5) - 458	407	11
Selenium	(0.46)	0.04 - 1.4	(0.4) - 0.61B	407	0
Silver	(0.68)	NA - 1.4 ^h	(0.64) - 44.3	407	18
Thallium	(0.42) - 0.46B	(50) - 0.8 ⁱ	(0.4) - 0.68B	407	0
Zinc	20.2 - 46.5	17.2 - 176.2	2.7B - 17,400	407	26

- Notes:
- ^a Background locations are BG-001 and BG-002; two samples were collected at each location.
 - ^b Based on the geometric mean and the geometric deviation from Shacklette and Boerngen (1984). Mean divided by two deviations (M/D^2) = lower range; mean multiplied by two deviations ($M \times D^2$) = upper range. About 95 percent of the samples in a randomly selected suite should fall between the lower and upper range.
 - ^c The number of samples greater than the instrument detection limit (IDL) that exceed the upper background range. The IDL represents the lowest concentration that can be reliably distinguished from the background noise of the instrument.
 - ^d Value in parentheses indicate the metal was not detected at the reported IDL.
 - ^e B indicates the value is greater than the IDL but less than the Contract Required Detection Limit (CRDL).
 - ^f Not Available.
 - ^g The upper background range for cadmium is estimated at 2.8 which is based on twice the observed mean for the four Plant 4 background samples.
 - ^h The upper background range for silver is estimated at 1.4 which is based on twice the IDL observed for the four Plant 4 background samples.
 - ⁱ The upper background range for thallium is estimated at 0.8 which is based on twice the IDL observed for the four Plant 4 background samples.

Soil samples were collected above the saturated zone from both well borings and analyzed for VOCs, total petroleum hydrocarbon, and various metals. The laboratory analyses did not detect any VOCs or hydrocarbons. Inorganic concentrations were found to be within the background range for metals in the United States (Intellus 1986b). Evaluation of data from F-218 and F-219 did not confirm the presence of Chrome Pit No. 1.

Intellus also drilled two shallow soil borings above the saturated zone (FB-5 and FB-6) at the southwest corner of the Process Building No. 181 in the reported vicinity of Chrome Pit No. 2 (Plate 3). Laboratory analysis did not detect any VOCs and the level of metals present were within the mean range typical for native soils (Intellus 1986b).

In 1986, Radian installed monitoring well HM-103 east of Chrome Pit No. 1 at the northeast corner of Building 188 (Plate 3). Soil samples collected from the saturated zone were analyzed for VOCs and inorganics; results indicate the presence of TCE at 65 and 170 $\mu\text{g/kg}$. Chromium concentrations were within the range of typical background values for soil. Radian also drilled monitoring well HM-104 at the southwest corner of Building 188. Soil samples from HM-104 were not submitted for chemical analysis.

From 1987 to 1989, Hargis + Associates drilled a number of Paluxy wells in the area of the Assembly Building/Parts Plant. No sample collections or analyses were reported.

Current Investigation: Previous investigations have concentrated on obtaining groundwater quality data or geotechnical information for the design of building foundations, therefore, the availability of chemical analyses of soil samples in historical data is limited. The main objectives of the PA/SI soil investigation at the Assembly Building/Parts Plant are to identify potential contaminated source areas present in the vadose zone that may have resulted from past manufacturing activities, to obtain chemical information on the nature of the contamination, and to delineate the extent of migration and environmental impact on subsurface soils.

Soil-gas measurements were collected approximately every 200 feet around the entire perimeter of the Assembly Building/Parts Plant to provide screening information on the nature of VOCs that may be present in the soils. Specific areas of potential contamination were then further investigated by drilling 35 soil borings and obtaining soil samples from the vadose zone and the saturated zone for chemical analyses. In some cases, the borings were completed as monitoring wells (see Section 1.5.5). Section 1.5.3.1 discuss the results of the soil-gas surveys and soil sampling, respectively.

Results of Assembly Building/Parts Plant Perimeter Soil-Gas Survey

The objective of the soil-gas survey in this area was to search for potential source areas of VOCs that would be indicative of environmental contamination associated with the manufacturing operations. Samples were collected on sorbent tubes approximately every 200 feet around the perimeter of the Assembly Building/Parts Plant and analyzed by the Geotech Analytical Laboratory for the TCL VOCs by EPA Method 8240. Samples were collected from a nominal depth of 4-feet-below ground level.

Limitations of the soil-gas measurements are dependent on the chemical and physical properties of the organic compounds, vadose zone characteristics, hydrogeologic parameters, meteorological conditions, and analytical instrumentation. Interpretation of the soil gas results are, therefore, considered qualitative.

Analytical results indicate that relatively low concentrations (nanograms per liter) of TCE, tetrachloroethene (PCE), and 1,1,1-TCA and various petroleum-related hydrocarbons (micrograms per liter) are present in the soil gas. Concentrations for the chlorinated compounds are summarized in Table 1-19 and posted in Figure 1-14. Dashed lines are subjectively drawn around the relatively higher concentrations to delineate anomalies that may be indicative of soil contamination. The patterns revealed

by the anomalies suggest two possible source areas for the solvents. One area is located at the south end of the Assembly Building/Parts Plant, just east of Building 12. TCE, PCE, and TCA are associated with this anomalous area. The other possible source area appears to be located near the center of the Assembly Building/Parts Plant, between Building 88 and Building 6. Anomalous concentrations of TCE, PCE, and TCA appear to originate near location SG-14 and SG-16 (see Figure 1-14).

Table 1-19. Summary of Total Petroleum Hydrocarbons and Chlorinated Solvents Measured in Soil-Gas Around the Perimeter of the Assembly Building

Parameter	TPH ($\mu\text{g/L}$)	PCE (ng/L)	TCE (ng/L)	1,1,1-TCA (ng/L)
Minimum	(0.003)*	(2.5)	(2.5)	(2.5)
Maximum	1,554	2,800	6,400	54
Total No. Analyses	55	55	55	55
No. Above Detection	53	20	26	33

Note: * Concentration in parentheses indicates the compound was not detected at the reported value.

Slightly elevated concentrations of petroleum-related hydrocarbons, including the aromatic compounds benzene, toluene, ethylbenzene, and xylene (BTEX) and relatively heavier molecular weight compounds such as naphthalene, cyclohexane, 4-methylnonane, methylcyclohexane, decane, pentane, and 1-ethyl-2-methylbenzene were also detected in the soil gas. Results of the measurements are summarized as TPH in Table 1-19 and plotted in Figure 1-15. These values represent the sum of all petroleum-related hydrocarbons that were detected by the Gas Chromatograph/Mass Spectrophotometer (GC/MS) measurement and include estimated and tentatively identified compounds.

The dashed lines in Figure 1-15 were subjectively drawn around values greater than 300 $\mu\text{g/L}$ to map areas having relatively high TPH concentrations. Two anomalous areas are revealed by these maps. The first TPH anomaly coincides with the southern-most solvent anomaly (see Figure 1-14). The highest value associated with this anomaly, 1,118 $\mu\text{g/L}$ TPH, is located at SG-45. This location is east of a 1,000,000-gallon fuel oil tank, suggesting leaking underground fuel lines are a possible source. Underground storage tanks (USTs) 19 and 20 are also located close to this anomaly, however, they are not considered a possible source because historically they did not contain fuel oil.

The second TPH anomaly occurs at the north end of the Assembly Building/Parts Plant, just east of Building 95 and Building 176. This anomaly does not appear to be associated with a solvent source. The highest TPH value in this anomalous area, 1,554 $\mu\text{g/L}$, was measured at location SG-30. This location is east of abandoned underground JP-4 fuel lines that may be a possible source for this anomaly.

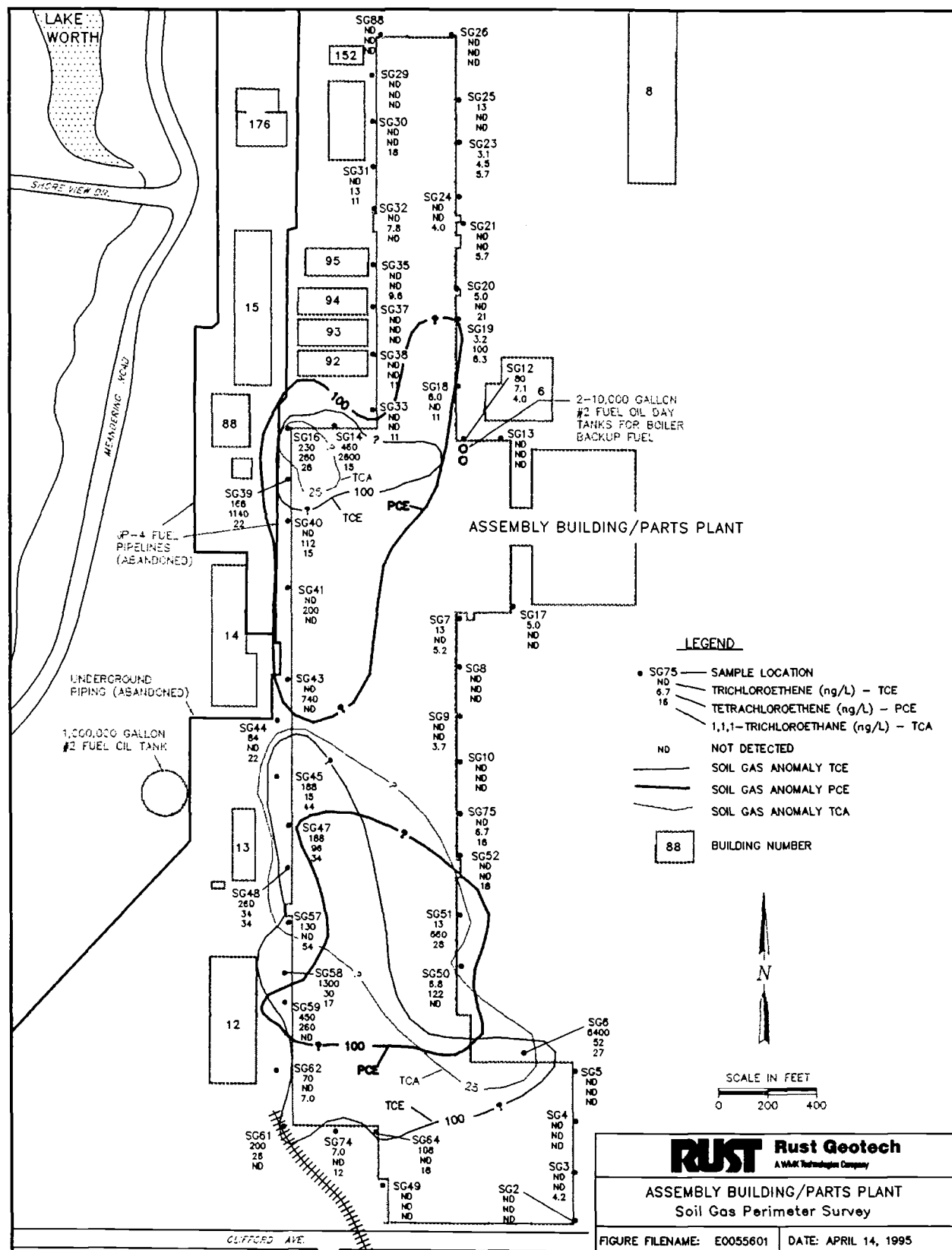


Figure 1-14. Results of Chlorinated Volatile Organic Compounds Detected in the Soil Gas.

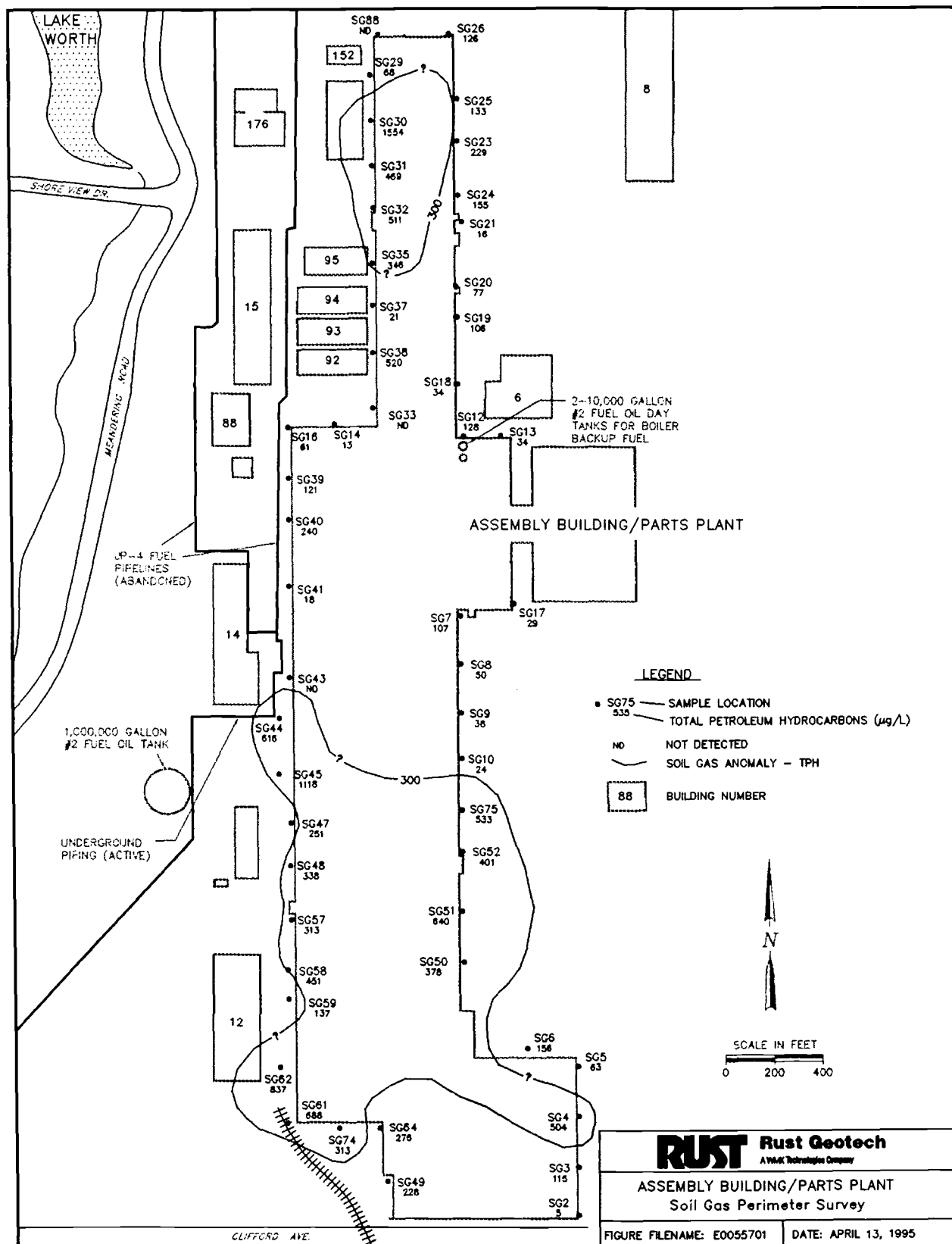


Figure 1-15. Results of Total Petroleum Hydrocarbons Detected in Soil Gas.

Results of Assembly Building/Parts Plant Borehole Soil Sampling

Soil borings were drilled at 35 selected locations to confirm the anomalous chlorinated hydrocarbons and to further evaluate the extent of the petroleum-related hydrocarbons that were detected in the soil gas. The borings were drilled with a truck-mounted, hollow-stem auger rig, from the ground surface to the top of the water table or until bedrock was encountered. Unconsolidated material was collected in 3-inch by 24-inch stainless steel-split barrel samplers for the entire borehole. Borehole lithology and sampling intervals are summarized in Appendix A-2 of the RI. Samples were composited from each 5-foot interval and analyzed for semi-VOCs, TPH, and inorganics. From each 5-foot interval, one grab sample was collected for VOC analyses. Appendix E of the RI presents a summary of the analytical data.

VOC and TPH Soil Sample Analyses: VOC and TPH analytical results for the soil samples are summarized in Table 1-20. The only VOCs reported above the CRQL that are associated with the samples are TCE and dichloroethene (DCE). Acetone and 2-butanone were also detected, but because these compounds occur randomly and are common laboratory contaminants (EPA 1988), they are probably not associated with the environmental samples. In addition, a relatively high concentration of 2-butanone (10,000 µg/L) was detected in the methanol used to decontaminate the sampling equipment (see Section 1.5.2).

Table 1-20. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from the Assembly Building/Parts Plant

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Cis-1,2-Dichloroethene	(5)	30	24	3
1,2-Dichloroethene (total)	(5)	46	112	2
Trichloroethene	(5)	220	136	26
Acetone	(10)	160	136	19
2-Butanone	(10)	180	136	18
Total Petroleum Hydrocarbons	(10) mg/kg	1741 mg/kg	98	12

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene was identified in the risk assessment as a chemical of concern.

Posted by each borehole location shown in Figure 1-16 are the results of the VOC and TPH analyses (excluding acetone and 2-butanone). Boreholes SB-035 and SB-036 were drilled to test the soils for the presence of petroleum-related compounds that were delineated by the soil-gas anomaly at the north end of the Assembly Building/Parts Plant. These borings were terminated in bedrock and the saturated zone, respectively. Contamination was not detected in any of the samples.

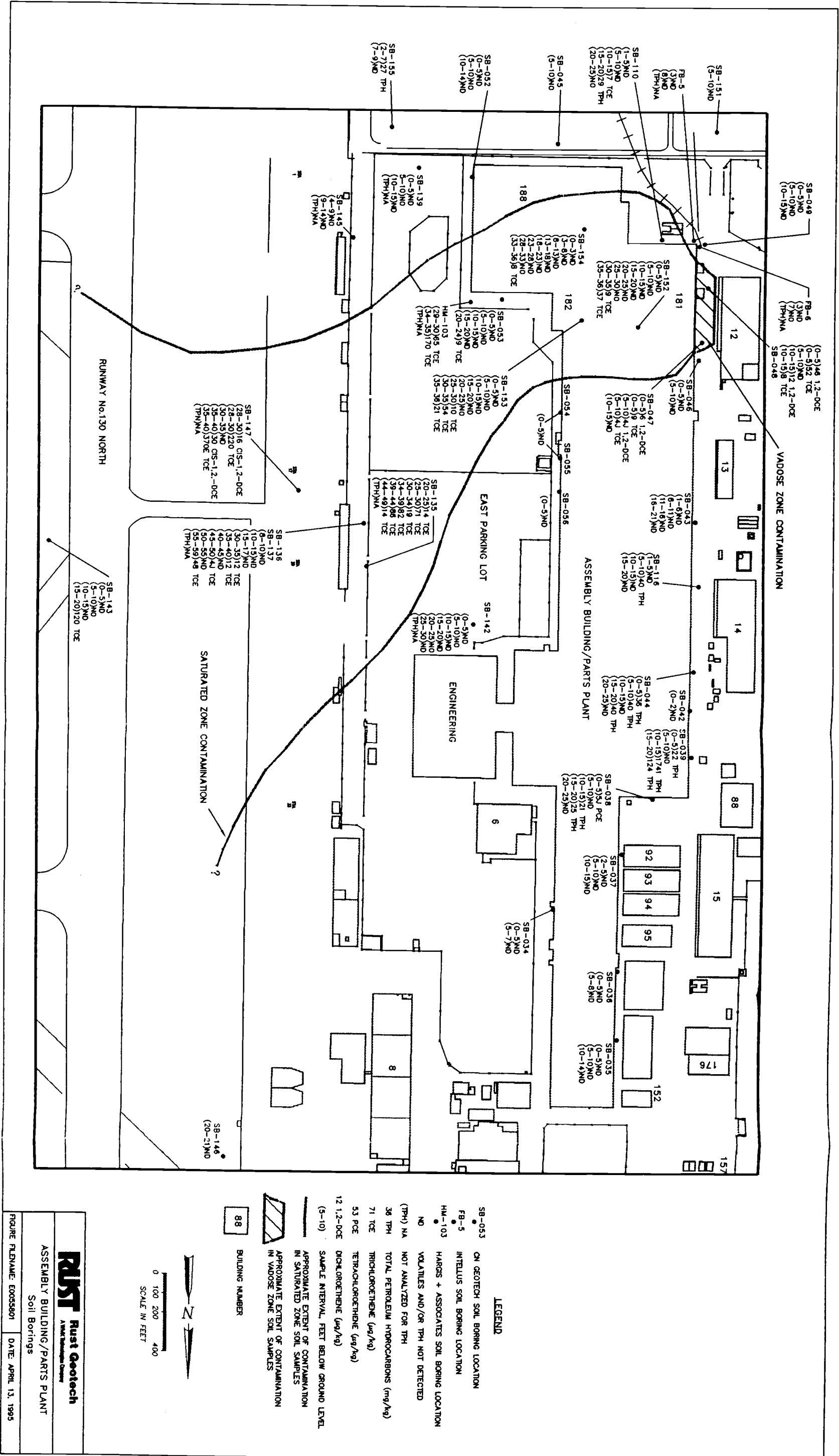


Figure 1-16. Soil Sample Analytical Results for VOCs and TPH.

Boreholes SB-034, -037, -038, -039, -042, -043, -044, and -116 were drilled to test the soils for the presence of TCE, PCE, and TCA, which were identified by the soil-gas anomaly located near the center of the Assembly Building/Parts Plant, between Building 88 and Building 6. The only chlorinated solvent detected in soil samples collected from these boreholes is PCE, at a concentration of 5J $\mu\text{g/kg}$ (see Figure 1-16). Although this value is qualified as an estimated quantity (J) and, therefore, not listed in Table 1-21, the soil sample location (SB-038) coincides with the location where the highest PCE value was detected in soil gas (SG-14, Figure 1-14). No other VOCs were detected in any soil sample from these boreholes.

Relatively low concentrations of TPH, 21 and 25 mg/kg, were detected in SB-038. TPH was also detected in SB-039, -044, and -116. This contamination is associated with leaking underground fuel lines in the area designated as Fuel Saturated Area No. 1 (FSA-1). For ease of presentation, TPH results associated with these three boreholes are discussed with results of the soil sampling conducted at FSA-1 (See Section 1.5.3.11).

SB-046, -047, -048, and -049 were drilled east of Building 12 in a north to south line, respectively, where numerous above ground solvent tanks are present. These four borings penetrated approximately 10 to 15 feet of unconsolidated material before terminating in bedrock. Groundwater was not encountered in any of these borings. Contamination was not detected in any soil sample obtained from the north boring (SB-046) or from the south boring (SB-049). Relatively low concentrations of TCE and 1,2-DCE (total), ranging from 8 to 52 $\mu\text{g/kg}$ and 6 to 46 $\mu\text{g/kg}$, respectively, were detected in soil samples obtained from SB-047 and -048. Since saturated soils were not encountered, soil contamination occurs only in the vadose zone and appears to decrease with depth, which suggests the source is related to surface spills and/or to shallow underground solvent tanks and associated piping. The area of vadose zone contamination, shown in Figure 1-16, is approximately 100-feet wide and 400-feet long. Assuming five feet as an average depth of contamination, approximately 7,400 cubic yards of soil may be impacted.

Table 1-21. Summary of Semi-VOC Results for Soil Samples Obtained from the Assembly Building/Parts Plant

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
bis(2-ethylhexyl)phthalate	(690)	3,900	137	28
Pyrene	(690)	2,200	137	2
Benzo(g,h,i)pyrene	(690)	1,000	137	1
Indeno(1,2,3-cd)pyrene	(690)	890	137	1
Benzo(b)fluoranthene	(690)	1,300	137	1
Fluoranthene	(690)	1,700	137	2
Benzo(k)fluoranthene	(690)	1,400	137	1
Chrysene	(690)	1,400	137	2
Phenanthrene	(690)	1,000	137	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene and fluoranthene were identified in the risk assessment as chemicals of concern.

Results of previous investigations, as well as the soil-gas survey (See Section 1.5.3.1), and the presence of TCE and TPH within the unsaturated zone between the 10- and 20-foot interval at SB-110 suggest soil contamination is much more extensive than the area of vadose zone contamination outlined in Figure 1-16. In fact, much of the data indicate that extensive TCE contamination may extend under most of the south end of the Assembly Building/Parts Plant. To test the soils under the facility, SB-152, -153, and -154 were drilled through the concrete floor slab in low traffic areas to minimize impact on daily plant operations. In all three boreholes, TCE was encountered in the saturated soils before terminating in the underlying Walnut Formation; however, TCE contamination was not encountered in any soil sample obtained above the saturated zone. This suggests that soil contamination in the vadose zone is not widespread beneath this portion of the facility but still may occur in localized areas as the result of downward migrating contaminants in the unsaturated zone immediately below potential sources such as underground solvent piping, drains, and degreasing tanks. Soil boring SB-110 indicated the presence of TCE and TPH within the unsaturated zone between the 10- to 20-foot depth interval. The greatest potential for isolated source areas is associated with the numerous acid, solvent, and degreasing tanks located within Chemical Process Building 181. Some larger possible sources are shown in Figure 1-17.

Previous investigations have shown that TCE contamination in the alluvial groundwater system occurs east of the Assembly Building/Parts Plant and is controlled by an east-northeast trending paleochannel. Unconsolidated sediments within the paleochannel were tested to determine the vertical and horizontal extent of contamination in the vadose and saturated zones. Soil contamination occurs mostly within the saturated zone of the paleochannel, as evidenced by the vertical distribution of TCE measured in boreholes SB-152, -153, -154, -053, and -143 (Figure 1-16). *Cis*-1,2-DCE, detected in SB-147, is the only other organic compound detected.

Control on the southern extent of soil contamination is provided by boreholes SB-151, -045, -052, -139, -155, and -145. Contamination was not detected in any of these borings except for an isolated occurrence at SB-155 where relatively low values of 27 mg/kg TPH and 4.7 mg/kg oil and grease were detected and at SB-151 where 65 mg/kg oil and grease were detected. The relatively low levels of TPH and oil and grease are isolated occurrences and are not related to the extent of TCE soil contamination associated with the alluvial groundwater system that flows within a paleochannel east of the Assembly Building. SB-151 and SB-155 established as background locations adjacent to Clifford Avenue, are relatively shallow in depth, and the TPH/oil and grease are most likely related to the asphalt avenue and vehicular traffic.

Control of the northern boundary of contamination is provided by boreholes SB-054 to -056, -142, and -146. The lateral extent of the saturated zone soil contamination shown in Figure 1-16 coincides in rough outline to the width and axis of the paleochannel (see Section 1.5.5).

Semi-VOC Soil Sample Analyses: A summary of the semi-VOC results is presented in Table 1-21. Bis(2-ethylhexyl)phthalate was reported above the CRQL for numerous cases, however, phthalates are common laboratory contaminants and most likely are not associated with the environmental samples (EPA 1988). This is supported by the duplicate analyses of the sample obtained at 15 to 20 feet from SB-039 that resulted in values of 2,200 and 210J $\mu\text{g/kg}$. This high variability (an order of magnitude difference) suggests laboratory contamination. Similar poor reproducibility is observed in duplicate samples collected at SB-036 and -046. Other boreholes where bis(2-ethylhexyl)phthalate was reported above the CRQL are SB-034, -035, -049, -116, -143, -152, -153, and -154.

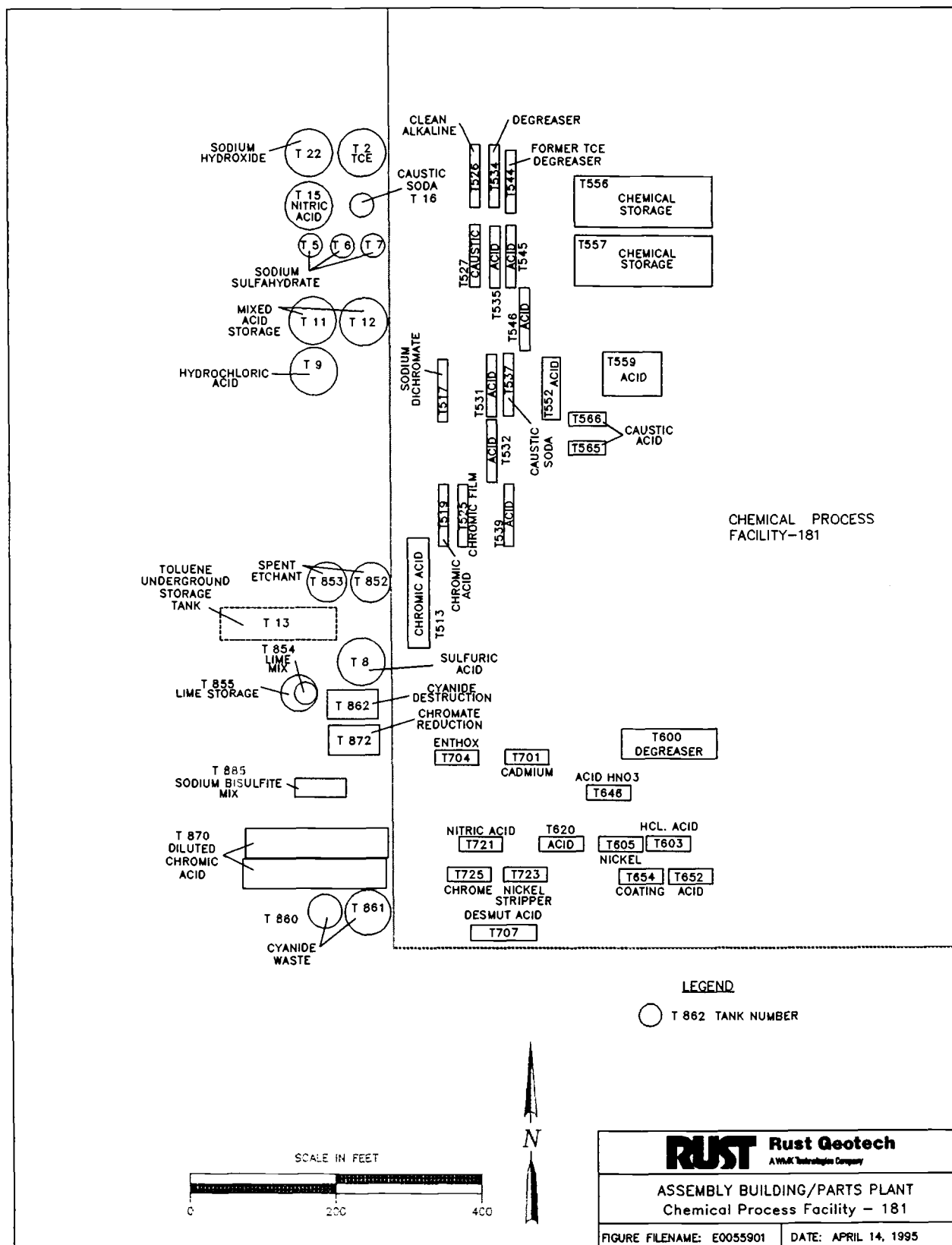


Figure 1-17. Potential Source Areas Associated with the Chemical Process Facility.

Several other semi-VOCs such as pyrene, fluoranthene, phenanthrene, and chrysene were reported once or twice above the CRQL. This group of compounds is typically associated with coal tar and crude oil. Because these compounds were detected only in the shallow 0- to 5-foot samples obtained from SB-035 and -055, they are probably the result of very small pieces of asphalt pavement incorporated in the sample and do not indicate contamination associated with manufacturing operations. In either case, they do not represent a significant environmental contaminant.

Semi-VOCs 1,3-dichlorobenzene, pentachlorophenol, and N-nitrosodi-N-propylamine were not detected above the CRQL but were reported as estimated quantities (qualified "J") in three instances (SB-036, -039, and -046). These compounds are typically associated with insecticides, pesticides, and herbicides. The isolated and limited occurrence of these compounds, combined with the fact that duplicate samples do not confirm their presence, suggest they are not associated with environmental contamination. This is evidenced by the duplicate analyses obtained at SB-039 and -036. In the first case, pentachlorophenol was not detected in the first sample, but the duplicate analysis was reported at 860J $\mu\text{g/kg}$. Similarly for the second case, N-nitrosodi-N-propylamine was not detected in the first sample, but the duplicate analyses was reported at 94J $\mu\text{g/kg}$.

Inorganic Soil Sample Analyses: Results of the soil samples analyzed for priority-pollutant metals, summarized in Table 1-22, indicate four analytes were detected above the upper limit of natural background concentrations. Silver and lead were detected once above the upper limit of natural background at SB-155 and -034, respectively. Cadmium was detected three times (SB-034, -155, -137) and antimony was detected four times above natural background concentrations (twice at SB-044 and once at -049 and -116). The silver value and all the antimony values above natural background are greater than the IDL but less than the CRDL. In all nine cases the values are very close to the IDL or slightly above the upper limit of natural background. The values also appear isolated and occur randomly, suggesting they are elevated due to natural processes.

All values above the IDL for the remaining analytes are within the range expected for natural background concentrations.

Conclusions

Just east of Building 12, four boreholes (SB-046, -047, -048, and -049) were drilled in a north to south line, respectively, where numerous above-ground solvent tanks are present. These four borings penetrated approximately 10 to 15 feet of unconsolidated material before terminating in bedrock. Groundwater was not encountered in any of these borings. Relatively low concentrations of TCE and 1,2-DCE (total), ranging from 8 to 52 $\mu\text{g/kg}$ and 6 to 46 $\mu\text{g/kg}$, respectively, were detected only in the two center borings. In this area, soil contamination occurs only in the vadose zone, since saturated soils were not encountered, and decreases with depth which suggests the source is related to surface spills and/or to shallow underground solvent tanks and associated piping (Figure 1-16).

Relatively low concentrations of TCE (7 to 220 $\mu\text{g/kg}$) occur in saturated soils under most of the south end of the Assembly Building and extend east at least as far as Runway Number 130 North (Figure 1-16). The extent of TCE migration in the saturated soils coincides in rough outline to the width and axis of an east-northeast trending paleochannel. *Cis*-1,2-DCE ranging from 16 to 30 $\mu\text{g/kg}$,

Table 1-22. Summary of Inorganic Sample Analyses for Soil Samples Obtained from the Assembly Building/Parts Plant

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for Western USA
Antimony	(8.4)	11.1B	2.2	135	4
Arsenic	(0.64)	10.7	21.6	135	0
Beryllium	(0.21)	1.4	3.6	135	0
Cadmium	(0.84)	4.6	2.8	135	3
Chromium	1.6B	29.2B	196.6	135	0
Copper	1.3B	55.1	90.0	135	0
Lead	0.87	100	55.1	135	1
Nickel	(3.5)	35.4	66.2	135	0
Selenium	(0.42)	(4.9)	1.4	135	0
Silver	(0.64)	1.6B	1.4	135	1
Thallium	(0.42)	0.68B	0.8	135	0
Zinc	4.5	111	176.2	135	0

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc have been identified in the risk assessment as chemicals of concern.

was detected in SB-147. This soil boring, located near the center of the paleochannel, is also the location where the highest TCE concentration (220 $\mu\text{g/kg}$) was measured. No other VOCs were detected in the paleochannel.

Several semi-VOCs, such as pyrene, fluoranthene, phenanthrene, and chrysene were reported once or twice at levels slightly above the CRQL. This group of compounds, typically associated with coal tar and crude oil, is believed to be the result of small pieces of asphalt pavement incorporated in the sample and is not indicative of environmental contamination due to manufacturing operations.

TPH was detected in two soil borings at relatively low concentrations (27 and 29 $\mu\text{g/kg}$) at the south end of the Assembly Building/ Parts Plant. TPH was also detected in several borings located east of Building 14 (Figure 1-16). Results associated with these borings are presented in Section 1.5.3.11 (FSA-1).

All 135 samples analyzed for priority-pollutant metals were less than the upper limit of natural background soil concentrations with the following nine exceptions: silver (one sample), antimony (four samples), lead (one sample), and cadmium (three samples). However, for all nine exceptions, the values are very close to the IDL or slightly above the upper limit of natural background. In addition, occurrence of these values is isolated and random suggesting they are elevated due to natural processes.

1.5.3.2 Underground Storage Tanks (USTs) (removed)

Summary of Investigations

Previous Investigations: Prior to December 22, 1988, the effective date of Federal Subtitle I regulations, 14 USTs were removed at Plant 4. A total of 12 tanks contained petroleum products and two contained hazardous substances (Hargis + Associates 1989a). Following removal of the tanks, analyses of soil samples collected from the excavations indicated that 6 of the tank locations (Tank Nos. 19, 20, 24A, 24B, 25A, and 30) have contaminants present in the soil. No further remedial action was performed. After removal of the tanks, the excavations were backfilled and paved.

Tanks 19 and 20 will be discussed in conjunction with FSA-1, UST-30 with FSA-3, and UST-25A with the Jet Engine Test Stand (JETS). Tanks 24A and 24B will be discussed in this section. Locations of the removed USTs 24A and 24B are shown in Figure 1-18.

Tanks 24A and 24B were reported to contain gasoline, and each had a capacity of 8,000 gallons. Contaminants found in the soils during excavation and their maximum reported concentrations include 1,1,1-TCE (8 $\mu\text{g/kg}$), *trans*-1,2-DCE (15 $\mu\text{g/kg}$), PCE (270 $\mu\text{g/kg}$), ethylbenzene (11 $\mu\text{g/kg}$), methylene chloride (11 $\mu\text{g/kg}$), toluene (67 $\mu\text{g/kg}$), TCE (8 $\mu\text{g/kg}$), and total xylenes (160 $\mu\text{g/kg}$) (Hargis + Associates 1989a).

Current Investigation: Previous sampling at the former site of Tanks 24A and 24B was insufficient to determine the potential levels and extent of contamination associated with leaks and spills from the tanks. The tank area was evaluated as a potential source for groundwater contamination of the upper zone. Although preliminary sampling has shown that contamination exists, no attempt was made to characterize the extent of contamination prior to backfilling, grading, and paving. This site may have been a significant source of contamination to the soils and groundwater over the years.

As shown in Figure 1-18, three soil borings (SB-127, -128, and -130) were placed around the perimeter of the former UST location where contamination was reported. One of the soil borings (SB-129) was placed between the former locations of the two tanks. Water was encountered in SB-129 and -130. Soil samples were collected from 5-foot intervals with samples for VOCs collected as grab samples and the remaining samples collected as composites of the entire 5-foot interval. Composite soil samples were analyzed for semi-VOCs and petroleum hydrocarbons. Ten percent of the composite samples were also analyzed for metals. Lithology logs were completed as soil borings were drilled to determine the depth of excavation and to note any visible contamination.

Summary of Soils

The four soil borings were drilled to total depths ranging from 5.9 feet to 16 feet. The entire area surrounding the former UST site is covered with up to 1.5 feet of concrete, which is underlain by 0.5 foot to 2 feet of fine sand. The remainder of material encountered in the boreholes consists of clay and silty clay with the amount of gravel increasing with depth. It is likely that the unconsolidated material that was penetrated is fill material put in place during excavation of the USTs and construction of adjacent Building 12. Detailed lithology for the four borings may be found on the borehole logsheets included in Appendix A-2 of the RI. Groundwater was encountered at a depth of 9.5 feet in SB-130.

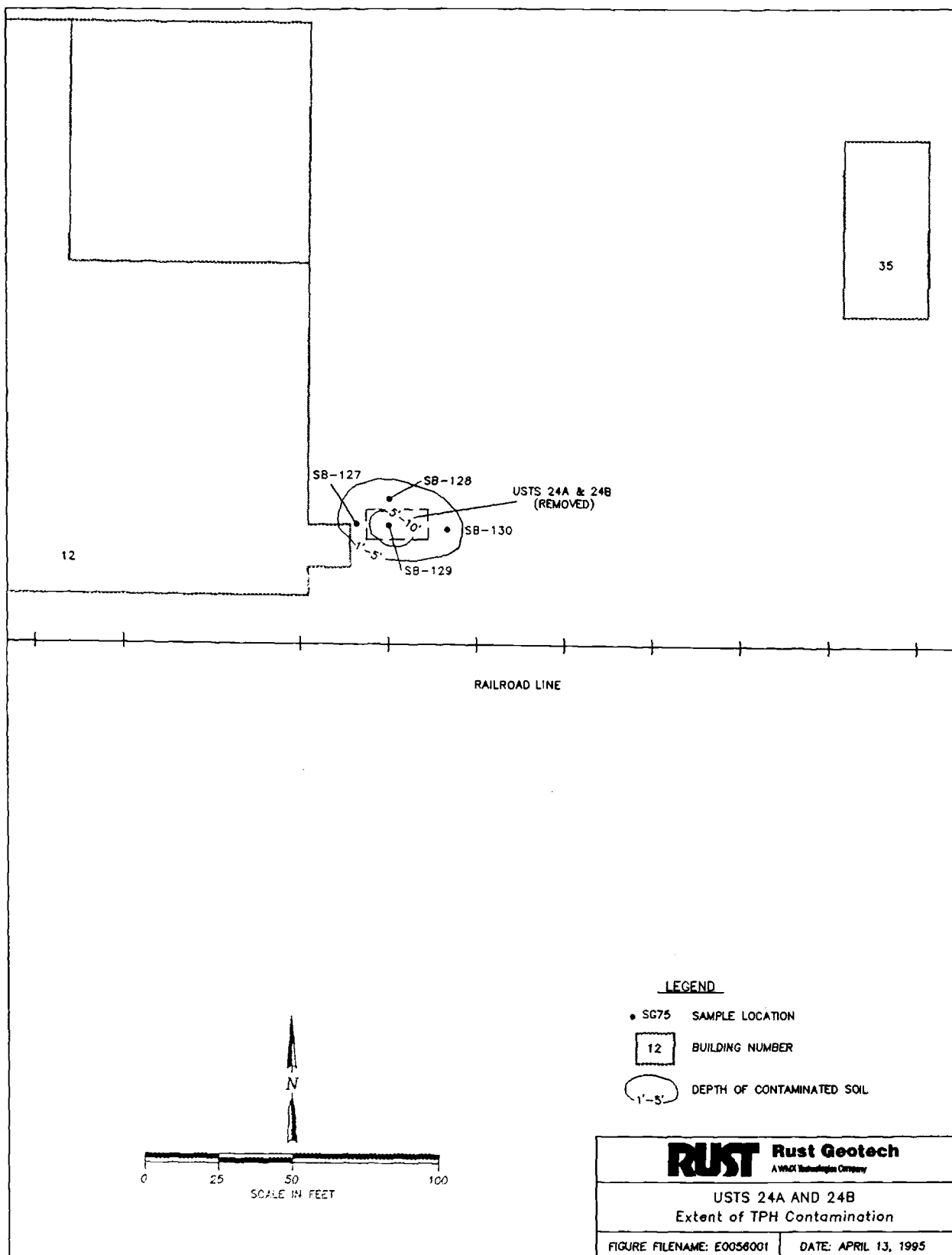


Figure 1-18. Extent of TPH Contamination at USTs 24A and 24B.

Results of the Investigation

Total petroleum hydrocarbons were detected in all four boreholes with a maximum concentration of 76 mg/kg found in the shallow (2 to 5.5 feet) interval of SB-127 (see Table 1-23 and the Appendix E of the RI). TPH was present in the top five feet of each borehole with the exception of SB-129 where the sample intervals from 5 to 15 feet are contaminated with hydrocarbons. The areal extent of TPH contamination is shown in Figure 1-18. There were no significant concentrations of VOCs or semi-VOCs detected at the site that may be correlated with the TPH. PCE was detected at a concentration of 9 $\mu\text{g/kg}$ in the 5- to 10-foot interval of SB-129. 2-Butanone is a common laboratory contaminant and was found in other laboratory blanks.

Table 1-23. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from USTs 24A & 24B

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
Tetrachloroethene	(6)	9	7	2
2-Butanone	12	160	7	5
Total Petroleum Hydrocarbons	(10) mg/kg	76 mg/kg	7	5

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Conclusions

Total petroleum hydrocarbons were found in samples from all four boreholes and are considered to be the only significant contaminant present at the former UST site. The total volume of TPH-contaminated soil in the vadose zone was calculated by using the area of extent (Figure 1-18) and the thickness (sample interval) of contamination. Based on the sampling and analyses, approximately 240 cubic yards of soil is estimated to be contaminated with hydrocarbons.

Concentration levels of metals were within the range for background soils of the western United States as shown in Table 1-24.

1.5.3.3 Landfill No. 1

Site History

From 1942 to approximately 1966, several types of hazardous and nonhazardous wastes were disposed in Landfill No. 1, which is located west of Facilities Building 14. This site encompasses about six acres and is presently the site of the West Parking Lot (Plate 1).

Table 1-24. Summary of Inorganic Sample Analyses for Soil Samples Obtained from USTs 24A and 24B

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background
Antimony	(9)	(9.8)	2.2	3	0
Arsenic	1.1B	2.4B	21.6	3	0
Beryllium	(0.22)	0.87B	3.6	3	0
Cadmium	(0.9)	1.8	2.8	3	0
Chromium	3.1	15	196.6	3	0
Copper	2.1B	6.7	90.0	3	0
Lead	4	8.1	55.1	3	0
Nickel	(5.6)	(6.1)	66.2	3	0
Selenium	(0.45)	(0.49)	1.4	3	0
Silver	(0.9)	(0.98)	1.4	3	0
Thallium	(0.45)	(0.45)	0.8	3	0
Zinc	4.9	23.3	176.2	3	0

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the risk assessment as chemicals of concern.

The majority of the waste disposed at Landfill No. 1 consisted of general refuse, rubble, plaster, lumber, and fill dirt. Potentially hazardous wastes were also disposed in the landfill. These included drums of unspecified liquid wastes, solvents, paint thinners, and paint wastes from tank trucks, all of which were dumped in shallow pits. Oils and fuels were also dumped in pits and subsequently burned. Aerial photographs show that at least five separate pits were located within the landfill. Sludge from these pits was periodically dredged out and deposited in the landfill area (Radian 1987). Other suspected wastes include mercury and magnesium wastes, chromate sludges, and cyanide.

The landfill was closed in 1966 when the area was graded and paved for vehicle parking. Prior to grading and paving, two 6-inch perforated pipes were laid in trenches on bedrock just east of Meandering Road. The pipes were intended to channel leachate from the landfill to a storm sewer (St. 5) outfall. When contaminants were identified in water samples collected from the St. 5 outfall in 1982, French Drain No. 1 was constructed to prevent contaminated groundwater from entering the storm sewer.

French Drain No. 1 was constructed in November 1982, east of Meandering Road, between Landfills No. 1 and No. 3. A 90-foot section of 4-inch perforated drain pipe was placed on bedrock east of the

St. 5 outfall. During excavation, the two 6-inch drain pipes were uncovered and rerouted to the French Drain No. 1 system. The 36-inch storm sewer and north catch basin were lined with polyethylene in late 1983 to eliminate infiltration of leachate to the storm collection system. The south collection basin was lined in February 1985. It should be noted that TCE and toluene both have "moderate" effects on polyethylene. Both of these contaminants have been identified in groundwater samples from nearby monitoring wells. A concentration of 25 $\mu\text{g/L}$ TCE was identified in water from the St. 5 outfall in April 1990.

In July 1983, a portion of Landfill No. 1 that contained several waste oil pits thought to be the main source of residual contamination was excavated, and the material was removed to an approved hazardous waste disposal facility as an interim remedial action. Approximately 11,000 cubic yards of contaminated soil were removed and transported to Chemical Waste Management's (CWM) Carlyss, Louisiana facility. Liquids were also removed from the excavation and disposed at CWM's Port Arthur, Texas facility. French Drain No. 2 was constructed within the excavation to intercept contaminated groundwater and pump it to a treatment facility on site. The excavation was then backfilled and the site repaved.

On-site treatment consisted of (1) processing the fluid through a cooling tower to volatilize organic compounds and (2) discharging the effluent to the city of Fort Worth sanitary sewer system. This system ceased operation in May 1990, at which time all pumping from the French Drains was halted (Hargis + Associates 1985a). In the spring of 1992, pumping began again using an activated charcoal treatment system on site.

On the basis of data from previous studies, the following contaminants with concentrations exceeding Federal maximum contamination limits (MCLs) were reported to occur in groundwater at Landfill No. 1:

- | | |
|----------------|------------------|
| ● Arsenic | ● Fluoranthene |
| ● Cadmium | ● PCE |
| ● Chromium | ● Toluene |
| ● Lead | ● 1,1,1-TCA |
| ● Acenaphthene | ● TCE |
| ● Benzene | ● Vinyl Chloride |
| ● Ethylbenzene | |

As evidenced by this list, Landfill No. 1 still contains petroleum hydrocarbons, waste solvents, and process chemical wastes. The interim remedial actions have eliminated only a portion of the potential source area for these contaminants.

Previous Investigations

Very little information is available pertaining to soils contamination in the landfill area. Previous investigations consisted of 22 test holes, 12 monitoring wells, and the Waste Oil Pits/French Drain excavations. Soil samples collected from the walls of the French Drain No. 2 excavation at completion indicated soils were still contaminated with VOCs and, at one location, chromium (EPA 1983). Soil samples taken during the drilling of F-216 and F-217 were screened with a photoionization detector (PID) to detect VOCs. The PID indicated VOCs were not present in F-216 but were present in trace amounts in F-217 at the 9- to 14-foot depth range (Radian 1987). Petroleum hydrocarbons were detected in both borings.

Current Investigation

During the current investigation, 16 soil borings were drilled and sampled in Landfill No. 1 to determine types and relative concentrations of contamination and to better define the extent of contamination. Drilling and sampling were halted at the water table or bedrock if no water was encountered. All borings were drilled using hollow-stem augers. No new groundwater monitoring wells were installed.

Figure 1-19 shows the borehole soil sample locations. Boreholes were drilled on a grid designed to cover the Landfill No. 1 area, as identified by previous investigations and old site photographs. The grid was extended when contamination was detected in boreholes outside the previously identified extent. Overhead high voltage lines in the southern section of the West Parking Lot prevented access to several planned drilling locations. Based on old (mid-1950s) aerial photos and borehole lithology, soil borings SB-012, -016, and -020 appear to have been drilled outside the landfill area. Contaminants in these borings are mostly shallow (0 to 5 feet) semi-VOCs related to asphalt or fuel oil.

Soil samples were composites of 5-foot intervals collected from the surface to the water table. Composite samples were analyzed for semi-VOCs, oil and grease, and metals. A grab sample for volatile organic analysis was collected from within the 5-foot interval where PIDs or visual examination indicated possible contamination.

Lithologic information taken from the existing monitoring wells and the soil borings was used to construct a bedrock surface contour map of the area under Landfills No. 1 and No. 3 (see Figure 1-20) and to construct two geologic cross sections (see Figure 1-21 and Figure 1-22) to illustrate the geology under the landfills. The cross sections show sand, clayey sand, and gravel layers that occur under much of the landfills.

The bedrock surface map indicates areas and direction for subsurface drainage of groundwater and contaminants. The bedrock map also shows the channels cut into the Walnut Formation that drain to Landfill No. 3 and Meandering Road Creek. Soils in the Landfill No. 1 area are mainly clays, silty/sandy clays, or sands. Fill material used to cover the landfill and grade the site ranges from sand to clay with some intermixed gravels and silts. Trash such as wood, plastic, wire, asphalt, glass, and metal was reported in ten of the 16 soil borings. Also indicated on the cross sections are areas where contamination was detected (see Appendix A-2 of the RI).

VOC and Oil and Grease Soil Sample Analysis: Table 1-19 shows 11 VOCs identified in Landfill No. 1 during the current investigation. VOCs detected were fuels, solvent, and solvent degradation products. Both toluene and TCE were detected and have been identified as chemicals of concern in the site risk assessment. The highest concentrations of VOCs were found in the areas adjacent to French Drain No. 2. Figures 1-23 and 1-24 show VOCs and oil and grease concentrations. The oil and grease threshold level for Figure 1-24 was set at 100 mg/kg (based on agreement discussions with the EPA and State of Texas). SB-023, located downgradient of French Drain No. 2, shows the highest VOC concentrations of all soil borings drilled in Landfill No. 1. An oily sheen was observed on the surface of the fluid in SB-023 at a depth of eight feet. Concentrations of toluene, 1,2-DCE, and 2-butanone in SB-023 were 350,000 µg/kg, 360,000 µg/kg, and 180,000 µg/kg, respectively, in the 8 to 10-foot-depth interval. The oil and grease analysis for the same interval was 6,878 mg/kg. This interval is directly above the bedrock surface (10-feet-below ground level) which is thought to both prevent deeper

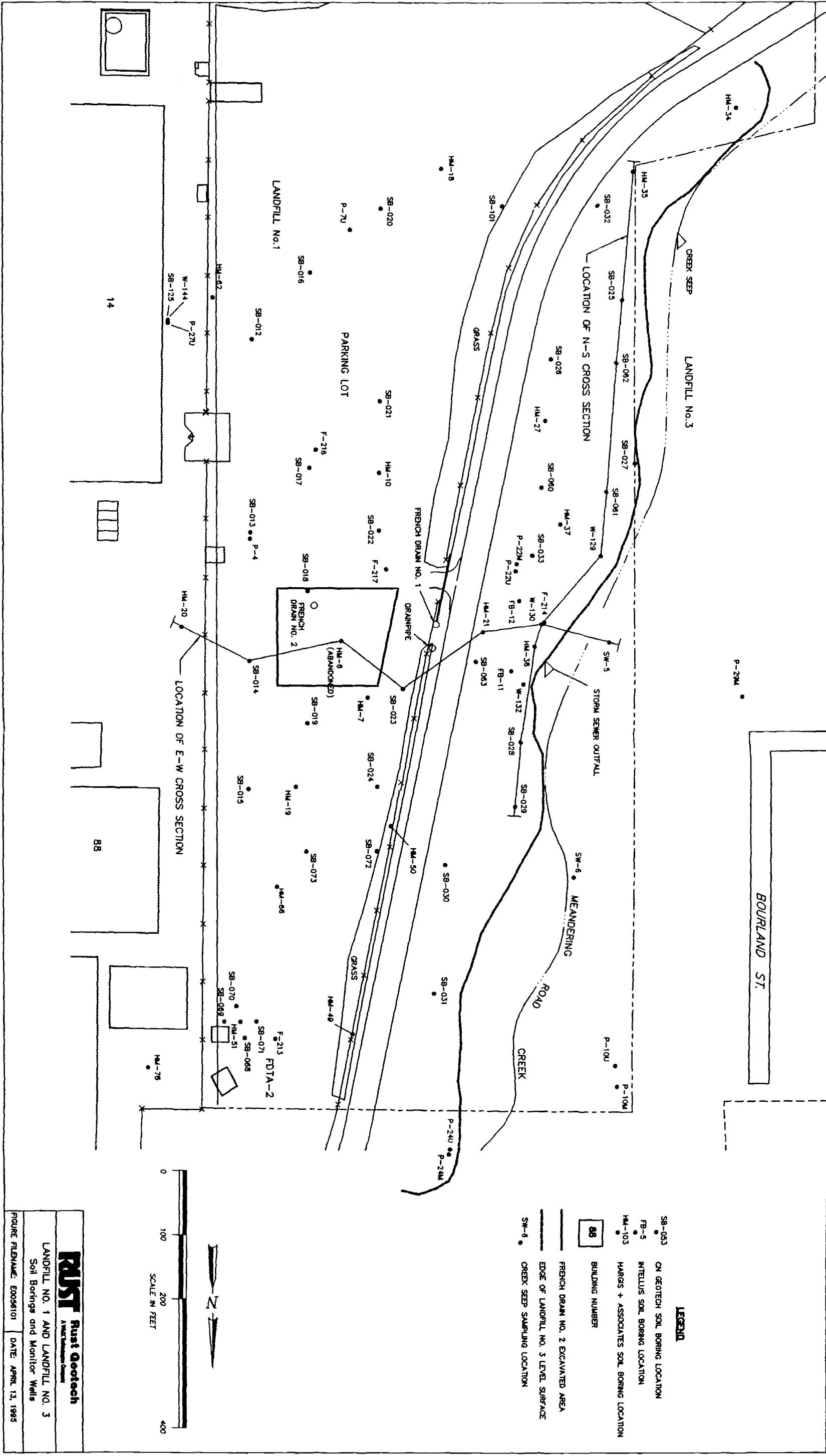


Figure 1-19. Borehole Soil Sample Locations at Landfills No. 1 and No. 3.

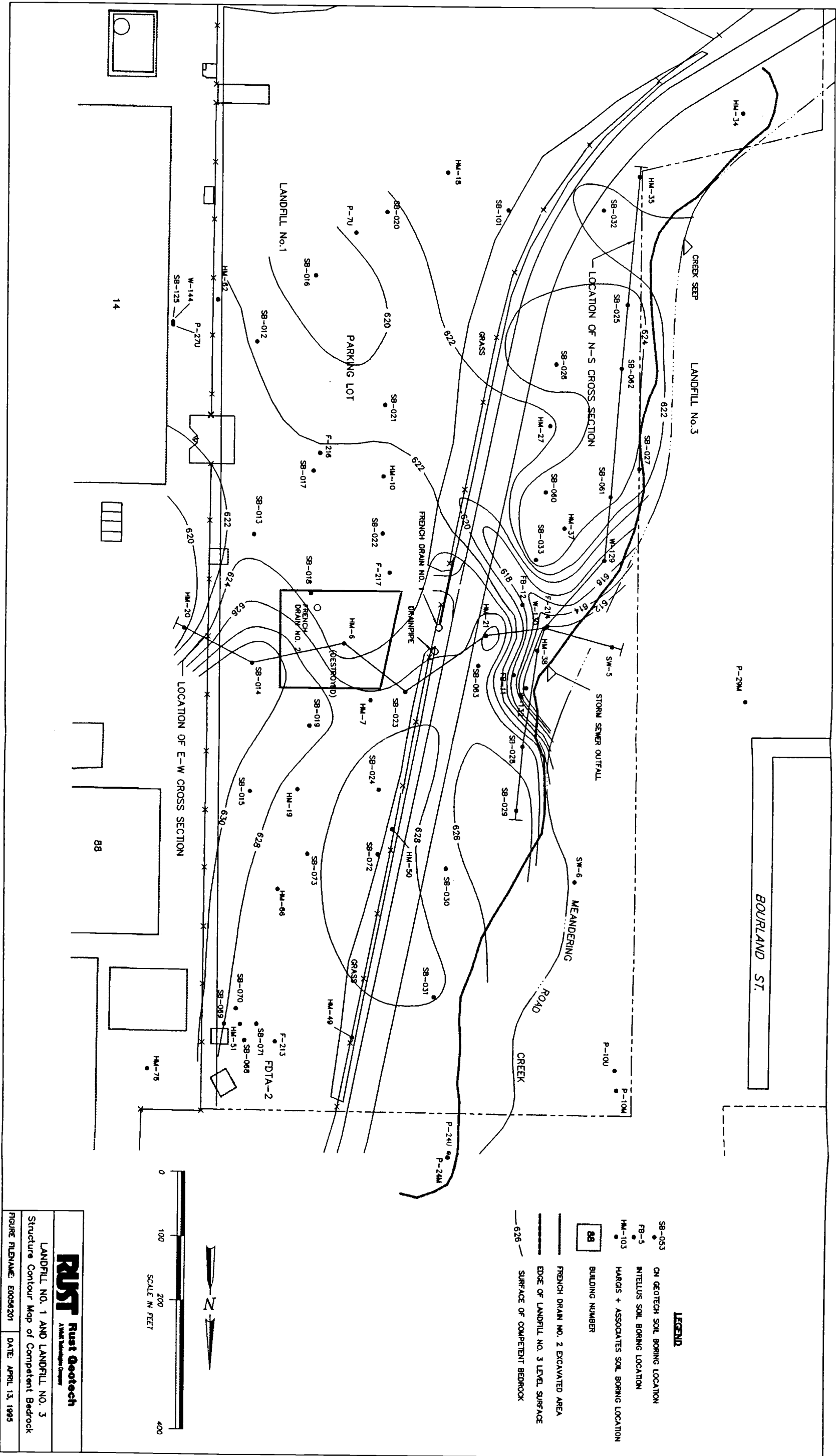


Figure 1-20. Bedrock Surface Contour Map for Landfills No. 1 and No. 3.

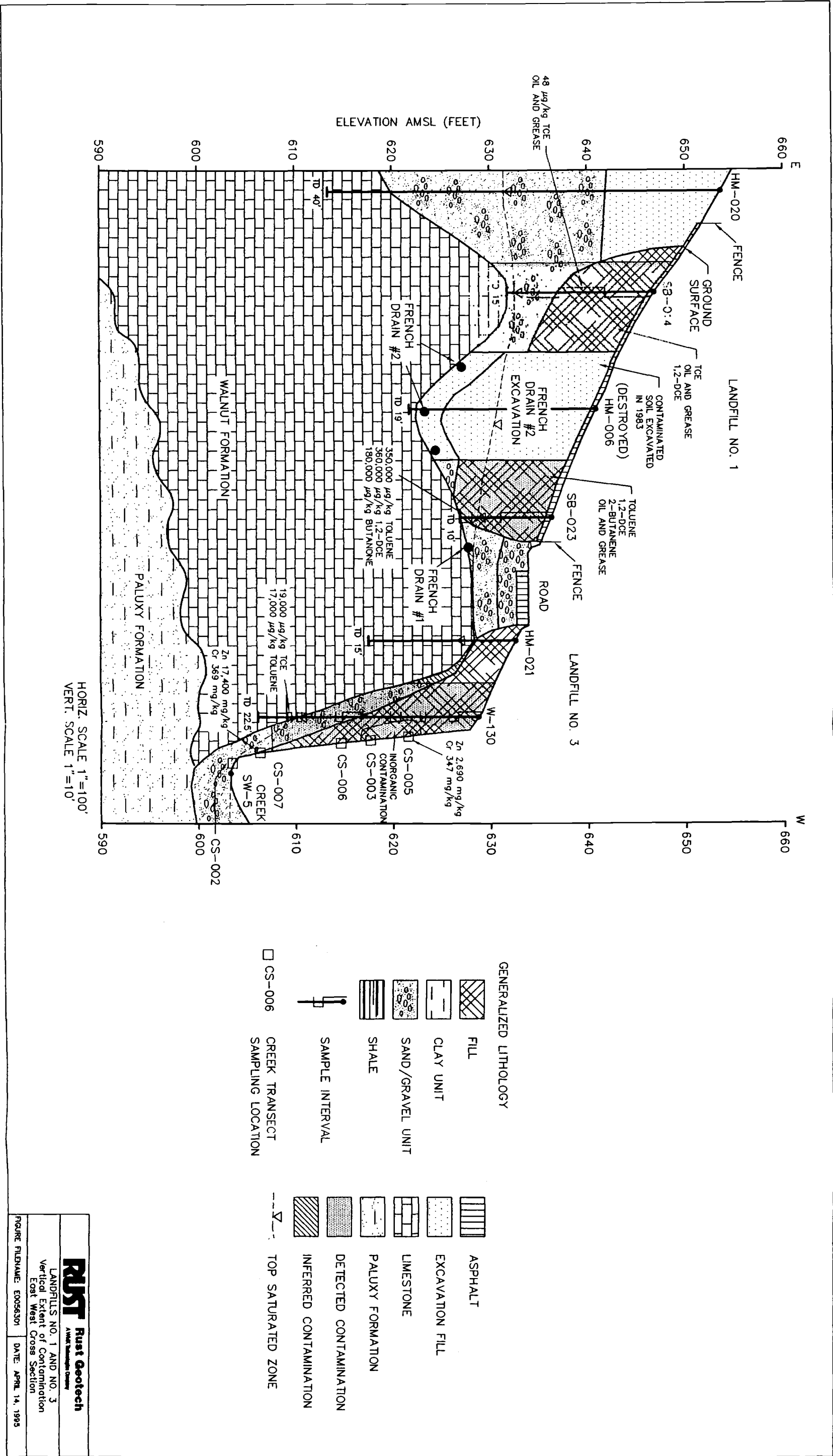


Figure 1-21. East to West Geologic Cross Section through Landfills No. 1 and No. 3.

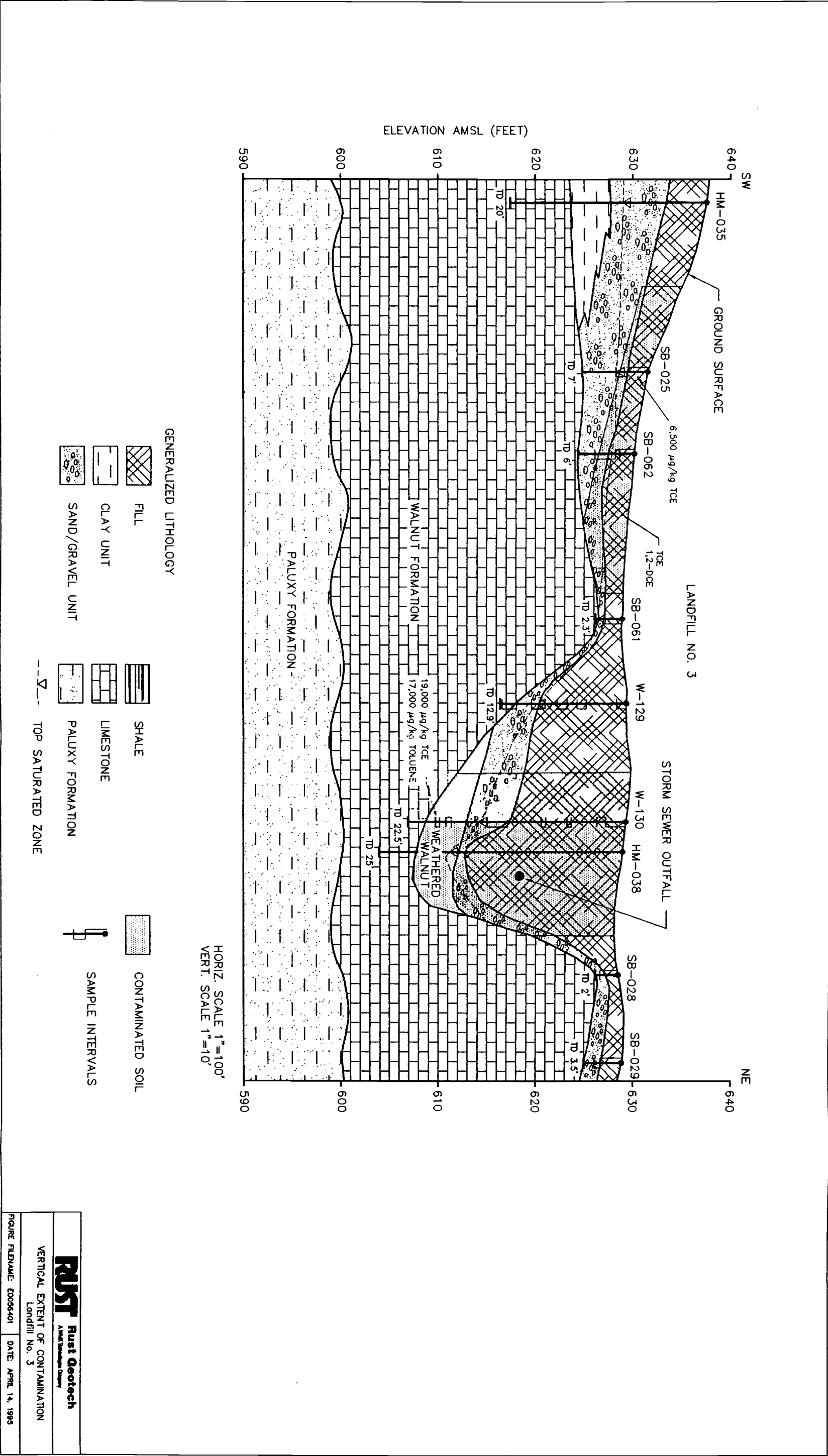


Figure 1-22. North to South Geologic Cross Section through Landfill No. 3.

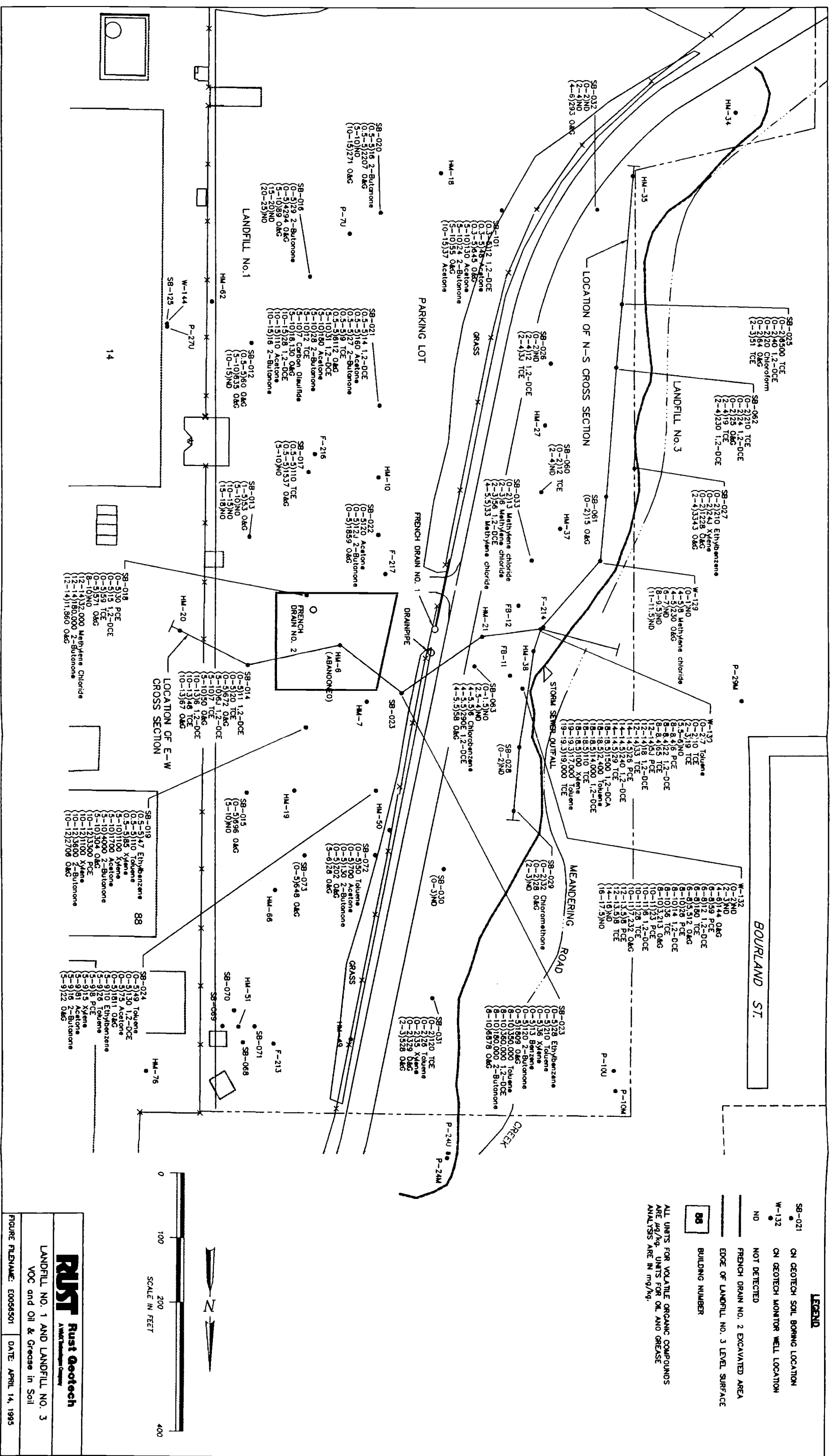


Figure 1-23. Soil Sample Results for VOCs and Oil and Grease Analyses at Landfills No. 1 and No. 3.

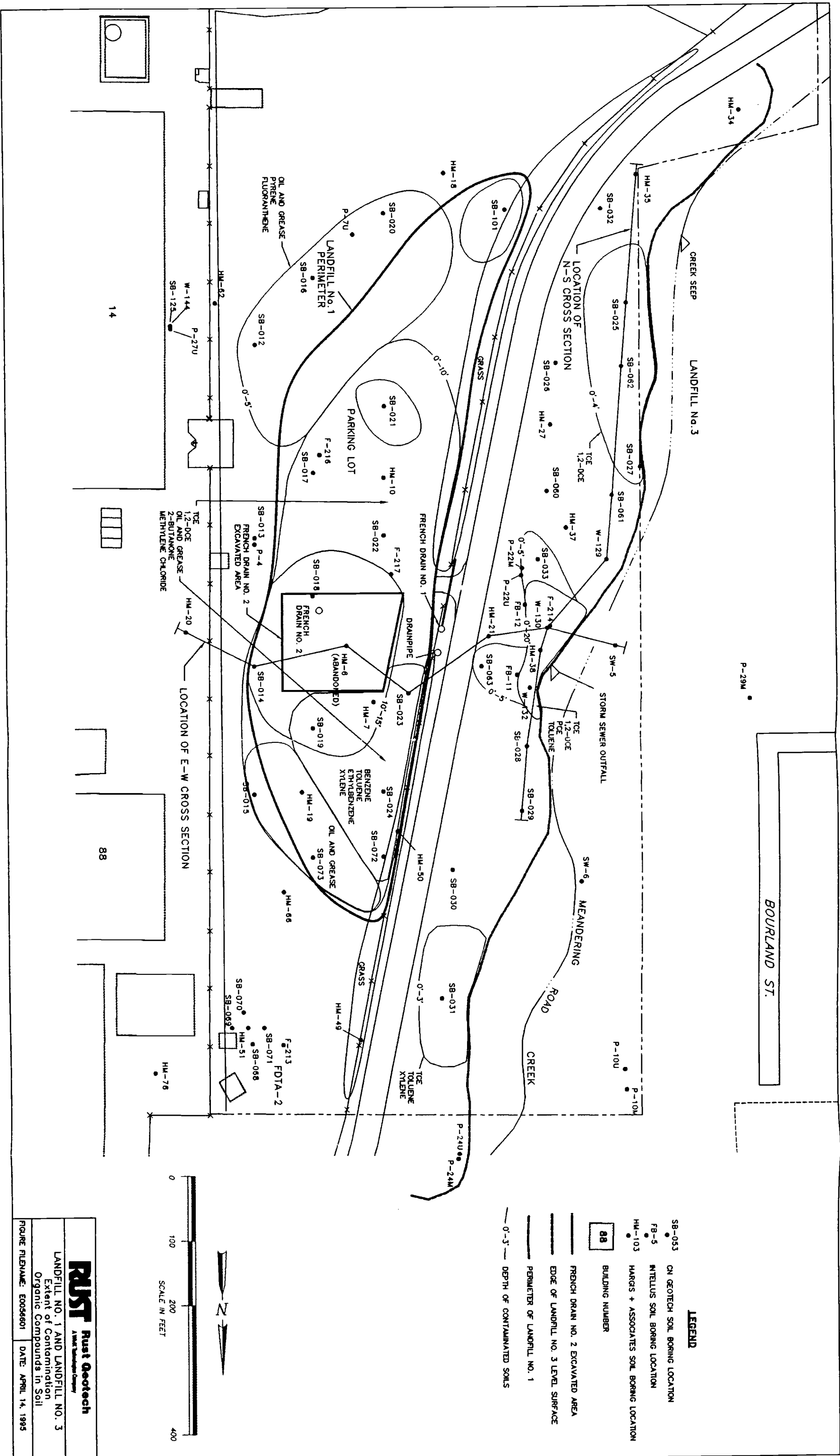


Figure 1-24. Extent of Organic Contamination in Soil Samples Collected at Landfills No. 1 and No. 3.

contamination, and in this area, channel the contaminants toward Meandering Road Creek (see Figure 1-20). Soil samples in the area northwest of the French Drain No. 2 excavation (SB-019, -023, and -024) indicate fuel-related products such as benzene, toluene, ethylbenzene, and xylene (BTEX) are present. These products were not detected in other Landfill No. 1 soil borings.

Oil and grease was reported in 36 samples collected across Landfill No. 1. Values for oil and grease ranged from none detected to more than 18,130 mg/kg (see Table 1-25). The highest values were found in soil borings adjacent to French Drain No. 2, which was the former location of waste oil pits. Oil and grease results from other borings across Landfill No. 1 were highest in the top sample of each borehole. Because all of the soil samples collected in Landfill No. 1 were taken from boreholes drilled through asphalt paving, the analytical results from near-surface samples probably reflect the asphalt paving or vehicular motor oil. Landfill No. 1 samples for oil and grease were composites of 5-foot intervals, which resulted in some loss of definition of the contaminated depth intervals.

Table 1-25. Summary of VOC and Oil and Grease Sample Analyses for Soil Samples Collected from Landfill No. 1

Analyte	Minimum μg/kg	Maximum μg/kg	No. of Samples Analyzed	No. Above CRQL
1,2-Dichloroethene	(5)	360,000	63	10
2-Butanone	(10)	180,000	65	20
Acetone	(10)	1,700	65	23
Benzene	(5)	13	65	1
Carbon Disulfide	(5)	12	65	3
Ethylbenzene	(5)	750	65	4
Methylene Chloride	(5)	32,000	65	2
Tetrachloroethene	(5)	3,300	65	3
Toluene	(5)	350,000	65	5
Trichloroethene	(5)	110	65	7
Xylene	(5)	1,600	65	7
Oil and Grease	(10) mg/kg	18,130 mg/kg	57	36

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene and toluene have been identified in the risk assessment as chemicals of concern.

Semivolatile Organic Compound Soil Sample Analysis: A summary of the Landfill No. 1 semi-VOC results is presented in Table 1-26. A total of 16 semivolatile compounds were detected in Landfill No. 1 during the soils investigation. All five semivolatile compounds identified as risk assessment chemicals of concern were detected.

The five compounds—pyrene, benzo(a)pyrene, fluoranthene, naphthalene, and 2-methylnaphthalene, were detected in samples across the landfill site. Figure 1-25 indicates locations and values of semi-VOC results. This figure does not include tentatively identified compounds or bis(2-ethylhexyl)phthalate, which is a common laboratory contaminant. Bis(2-ethylhexyl)phthalate was reported only once in Landfill No. 1 in SB-020 in the 5- to 10-foot interval at 1,700 $\mu\text{g}/\text{kg}$ and may be due to laboratory contamination as it does not appear elsewhere. It was tentatively identified in a duplicate sample of the same interval at 130 $\mu\text{g}/\text{kg}$, which is an order of magnitude less than the original sample.

The semi-VOCs appear to be in two areas of the landfill: either in the samples immediately below the asphalt paving, which would not indicate contamination from manufacturing operations, or in the samples collected from boreholes in the area near French Drain No. 2, the former waste oil pits location.

Several semi-VOCs such as pyrene, fluoranthene, chrysene, and phenanthrene are typically associated with coal tar and crude oil. These substances were detected across the landfill, usually in the sample interval immediately below the asphalt pavement and are probably the result of small pieces of asphalt incorporated in the sample.

The samples from SB-012, -013, -014, -015, -016, -017, -020, -024, -072, -073, and -101 have semi-VOC contaminants reported mainly in the samples collected immediately below the pavement. These borings had very few semi-VOCs reported in samples collected below the surface sample. Historical reports of "periodic dredging and depositing in the landfill" material from the former waste oil pits may also account for some of the semi-VOC contamination in these borings. The second set of borings, SB-018, -019, -021, -022, and -023, were located near French Drain No. 2, and have semi-VOC contaminants reported in samples collected at deeper depths. Contaminants from the second set of boreholes include compounds found in manufacturing processes such as benzoic acid and 1,2-dichlorobenzene.

Dibenzofuran, used in insecticides, was identified at low levels in four soil borings grouped at the south end of the landfill (SB-012, -016, -018, and -020) and in SB-072 on the north edge of the landfill. These analytical results were qualified with a "J" to indicate the concentration is an estimated quantity. The 0- to 5-foot sample collected from SB-016 had very high levels of polynuclear aromatic hydrocarbons that created problems with the laboratory's quality control internal standards. Analytical results from this sample interval were treated as estimated values.

Inorganic Soil Sample Analyses: Results of the inorganic analyses vary widely across Landfill No. 1. Sample results indicate contaminants that were dumped in the immediate area of the borehole and do not correlate well across the site. Samples with the highest analytical results are in areas where, based on old aerial photographs, dumping was known to occur. Samples from areas where dumping was not thought to occur generally indicate contaminant levels several orders of magnitude lower. Areas where dumping did not occur usually have higher levels of inorganics within five feet

Table 1-26. Summary of Semi-VOC Sample Analyses for Soil Samples Collected from Landfill No. 1

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
1,2-Dichlorobenzene	(700)	25,000	56	6
1,4-Dichlorobenzene	(700)	1,700	56	1
2-Methylnaphthalene	(700)	2,400	56	3
Anthracene	(700)	25,000	56	1
Benzo(a)anthracene	(700)	71,000	56	4
Benzo(a)pyrene	(700)	62,000	56	3
Benzo(g,h,i)perylene	(700)	53,000	56	3
Benzo(k)fluoranthene	(700)	58,000	56	6
bis(2-ethylhexyl)phthalate	(700)	2,500	56	3
Chrysene	(700)	87,000	56	4
Fluoranthene	(700)	190,000	56	7
Fluorene	(700)	1,800	56	3
Indeno(1,2,3-cd)pyrene	(700)	56,000	56	6
Naphthalene	(700)	2,300	56	6
Phenanthrene	(700)	150,000	56	6
Pyrene	(700)	150,000	56	5

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, benzo(a)pyrene, fluoranthene, naphthalene, and 2-methylnaphthalene were identified in the Baseline Risk Assessment as chemicals of concern.

of the surface and probably indicate some degree of smearing from when the landfill was graded and paved. All five inorganic risk assessment chemicals of concern are found in Landfill No. 1 as shown in Table 1-27. Figure 1-26 shows Landfills No. 1 and No. 3 inorganics that were reported at levels greater than the concentration ranges found in the Plant 4 background locations. SB-021 had very high analytical results for inorganics, with cadmium at 594 mg/kg, chromium at 808 mg/kg, copper at 2,550 mg/kg, nickel at 228 mg/kg, lead at 1,760 mg/kg, and zinc at 13,200 mg/kg. Arsenic, beryllium, and silver were also detected in SB-021 although at much lower levels. Except for chromium, which had its highest result in the 0.5- to 5-foot sample, all of the high values were detected in the 5- to 10-foot sample interval. This soil boring, which had low levels of VOCs, indicates again that contaminants in the landfill are irregularly located.

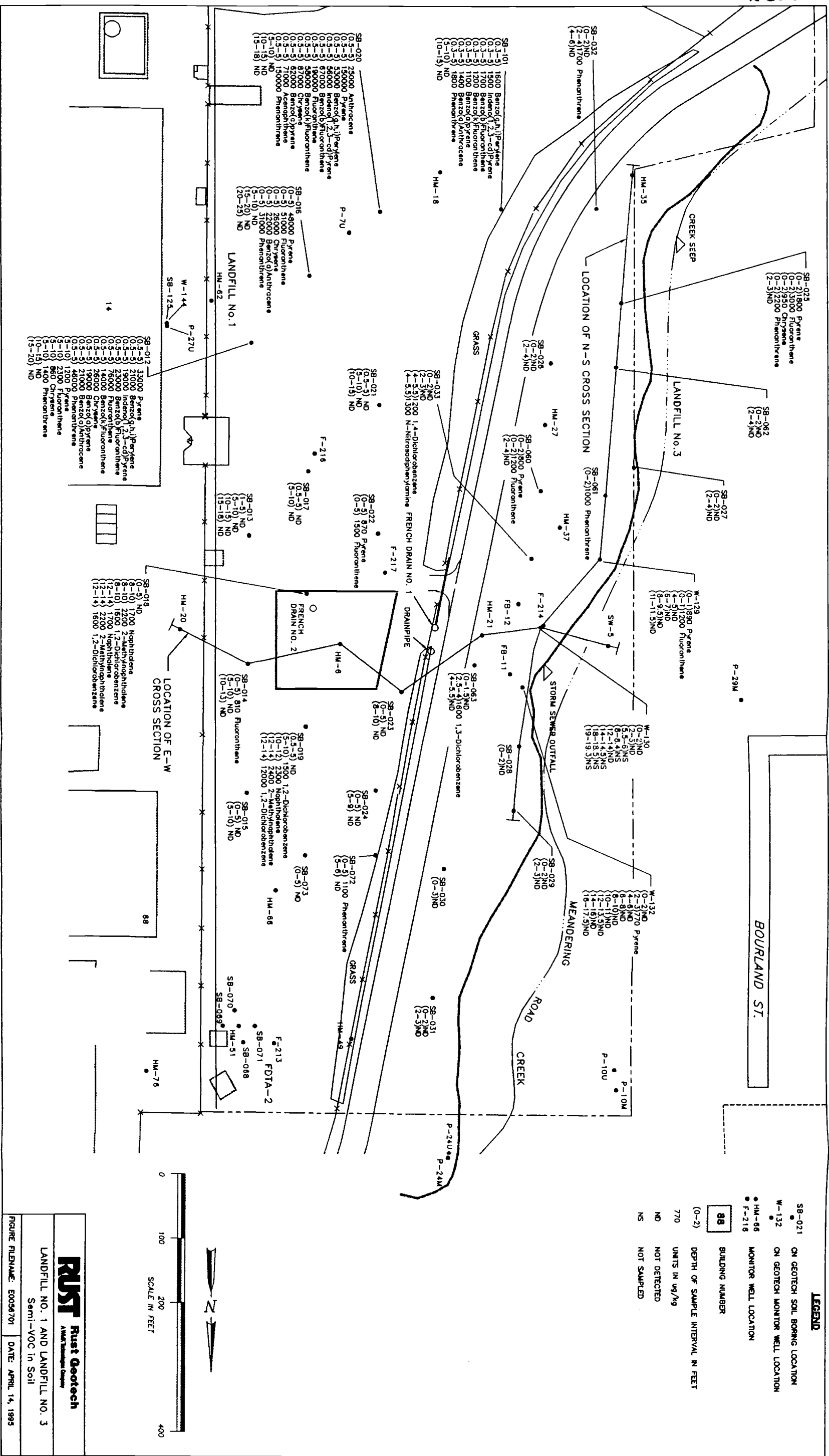


Figure 1-25. Soil Sample Results for Semi-VOC Analyses at Landfills No. 1 and No. 3.

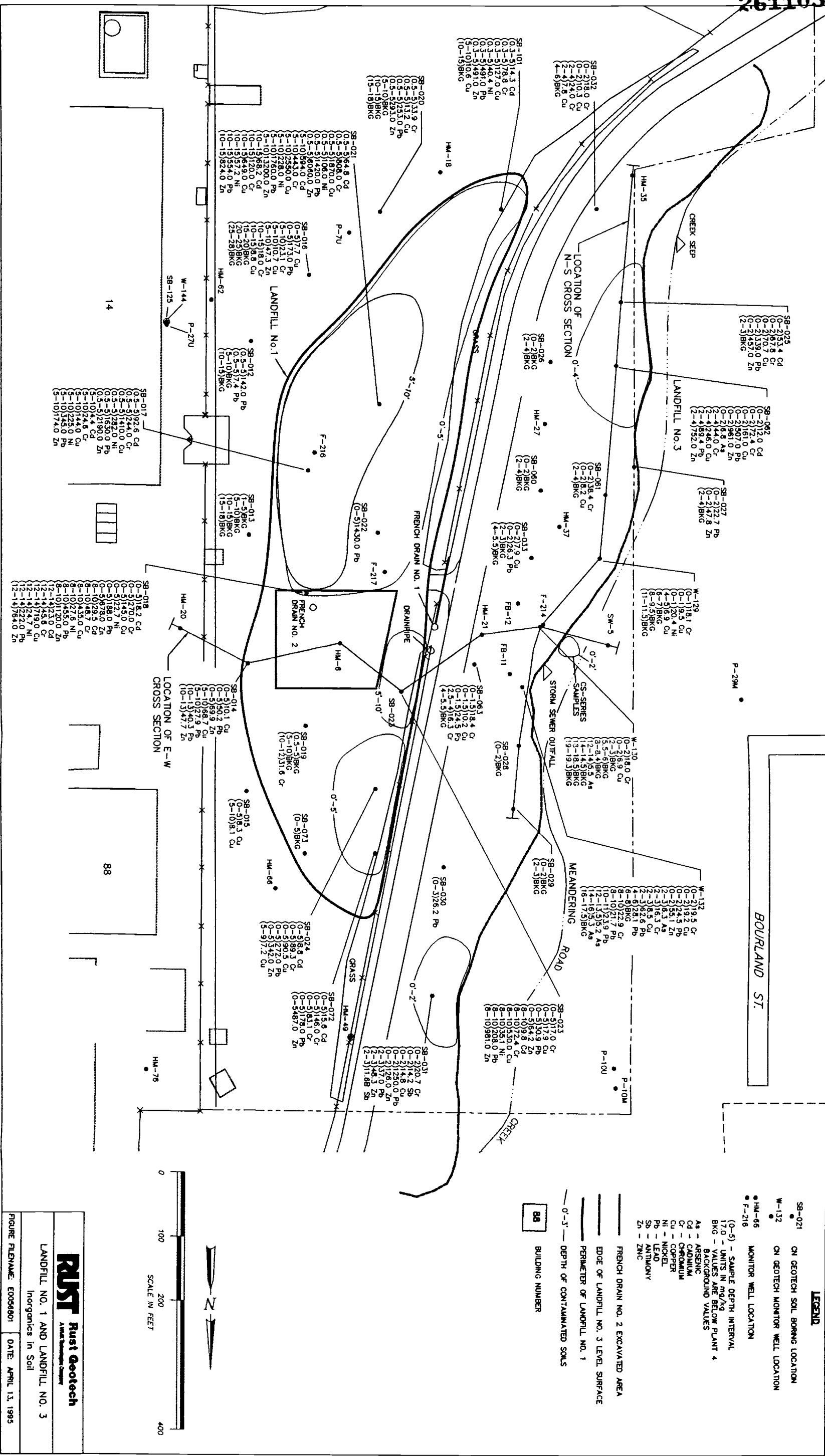


Figure 1-26. Extent of Inorganic Contamination and Results of Analyses for Soil Samples Collected at Landfills No. 1 and No. 3.

Table 1-27. Summary of Inorganic Sample Analyses for Soil Samples Collected from Landfill No. 1

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyz ed	No. Above Natural Background for Western USA
Antimony	(8)	77.5	2.2	57	2
Arsenic	(0.6)	13.8	21.6	57	0
Beryllium	(0.22)	1.1	3.6	57	0
Cadmium	(0.8)	594	2.8	57	12
Chromium	2.4	808	196.6	57	4
Copper	3.1B	2550	90.0	57	11
Lead	1.4	1760	55.1	57	16
Nickel	(5)	282	66.2	57	4
Selenium	(0.4)	(4.7)	1.4	57	0
Silver	(0.8)	44.3	1.4	57	9
Thallium	(0.4)	(0.55)	0.8	57	0
Zinc	2.7B2	13200 1	176.2	57 5	12 1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

Toxicity Characteristic Leaching Procedure (TCLP) Analytical Results: Toxicity characteristics leaching procedure analysis for VOCs, semi-VOCs, and inorganics were performed on a sample split from the 8- to 10-foot depth interval in SB-018. VOCs were not detected in the sample. Four semivolatile compounds and three inorganic compounds were detected (Table 1-28). The four semivolatile compounds all have results of 1 µg/L flagged with a J, which indicates an estimated value. Barium, cadmium, and lead are the inorganics that were detected. The B flag for barium indicates the value reported is less than the CRDL but greater than or equal to the IDL. All the semi-VOCs and the inorganic constituents that were detected in the sample are less than the regulatory TCLP levels.

Conclusions

A variety of soil contaminants remain in Landfill No. 1. High levels of solvents and solvent degradation products still exist in areas of the landfill. Fuel contaminants were found in the western section of the landfill downgradient of the former waste oil pits. Inorganic contaminants were detected irregularly

Table 1-28. TCLP Analytical Results

Semivolatile Constituent	Concentration in Extract
Hexachlorobutadiene	1J $\mu\text{g/L}$
Pentachlorophenol	1J $\mu\text{g/L}$
2,4,6-Trichlorophenol	1J $\mu\text{g/L}$
2,4,5-Trichlorophenol	1J $\mu\text{g/L}$
Inorganic Constituent	Concentration in Extract
Barium	338B $\mu\text{g/L}$
Cadmium	115 $\mu\text{g/L}$
Lead	577 $\mu\text{g/L}$

across the landfill and probably reflect what was dumped in the immediate area. Solvent compounds found in Landfill No. 1 soil borings have also been detected in Landfill No. 3 soil borings and monitoring wells downgradient of Landfill No. 1.

Volume estimates of contaminated soil were made based on Geotech soil sample analytical results, depths of samples, soil boring lithology, and historical photos of landfill use. Soil samples were collected as composites of 5-foot depth intervals, which means volume estimates based on 5-foot intervals may be high, (contamination from 0 to 6 feet would be reported as 0 to 5 feet and 5 to 10 feet). Contaminants detected in adjacent groundwater monitoring wells were also considered to be an indication of possible soil contamination. A threshold value of 100 mg/kg oil and grease was used to delineate extent of contamination if no other organic contaminants were detected.

Approximately 83,400 cubic yards of soil are estimated to be contaminated with organic compounds; of that an estimated 39,600 cubic yards are also contaminated with inorganic contaminants. These figures take into account the 17,000 cubic yards of material removed during the construction of French Drain No. 2, which was replaced with clean fill.

1.5.3.4 Landfill No. 3

Site History

Contamination was first detected at Landfill No. 3 in 1982 after a local citizen detected odors at a 36-inch storm drain that passed through the landfill and drained into Meandering Road Creek (St. 5 Outfall). Subsequent analysis of water samples collected from the outfall identified several contaminants, the most prevalent of which was TCE (Hargis + Associates 1985a). Remedial action resulted in the lining of the storm drain in late 1983 where it passed between the landfills, excavation of the former Waste Oil Pits (located in Landfill No. 1) in 1983, and the construction of French Drain No. 1 in November 1982 and French Drain No. 2 in 1984.

French Drain No. 1 was pumped daily with a vacuum truck to reduce the amount of groundwater infiltration into the outfall. French Drain No. 2 was equipped with an electric submersible pump that was activated in December 1984. Pumping continued until May 1990 when GD ceased treatment of the purged fluids. A new charcoal treatment system installed in December 1991 was operated for approximately three weeks before failure in January 1991 because of particulates clogging the equipment. The system was repaired and in operation several months later.

The landfill material is primarily soil fill of variable nature with clay, silt, sand, and gravel all being reported from drilling logs. Some plant material and trash are reported but do not appear to be major components. Asphalt and concrete rubble also occur but apparently only as smaller fragments that are not large enough to stop drilling. Large blocks of broken concrete are visible on the steep western slope of the landfill, apparently placed there to prevent erosion.

The fill was placed on top of both the alluvial deposits and on the Walnut Formation. Drilling logs indicate that the alluvial deposits are primarily present in the southern and central portions of the landfill. The alluvial deposits thin out from the south end to the central portion of the landfill. The alluvium and fill have a maximum thickness of 19 feet at HM-38, which is located in a drainage channel eroded into the Walnut Formation. This channel, which contains the storm sewer, was filled and graded in 1966 and 1967. A 1941 pre-landfill topographic map shows several such drainage channels cut into the surface under Landfill No. 3. Depth of the alluvium ranges from 2 to 7 feet over most of the landfill except where a previous drainage channel was filled in, as at HM-38, F-214, or HM-36. The lithologic logs for all three wells indicate a deep cut in the bedrock surface. A shallower drainage cut is also indicated at the southern end of the landfill near wells HM-26 and HM-27 (Intellus 1987). Figure 1-20, Bedrock Surface Contour Map for Landfills No. 1 and No. 3, shows the channel at this location. The drilling logs indicate that the alluvial deposits thin toward the center of the site and are absent in wells HM-21 and HM-39 and at the northern end of the landfill. These alluvial deposits are extremely variable even within the small area of Landfill No. 3, consisting of clay and sandy or silty clay in the southern portion of the landfill, grading to sandy gravel lenses, and then only sand and gravel at HM-26 and HM-27. Further north of these wells, the alluvial aquifer grades back to a clayey sand and gravel and then to a silty clay before disappearing from the top of the Walnut Formation. An east-to-west cross section of the landfill (Figure 1-21), indicates three general layers under the landfill: fill, a sand and gravel unit, and weathered bedrock. Figure 1-22 shows the geology of the western edge of Landfill No. 3. The cross sections also illustrate how the bedrock channels which are filled with several feet of weathered bedrock, sand, and gravel, act as conduits for the transport of contaminants across the landfill.

Previous Investigations

Fourteen soil test borings, ten alluvial monitoring wells, and six Paluxy monitoring wells were drilled in the Landfill No. 3 area during several investigations since 1982. Very few analytical results for soils were reported. Three additional temporary alluvial monitoring wells and 13 soil borings were drilled during the current investigation. GD drilled three soil borings near the center of Landfill No. 3 in 1982 to assess subsurface conditions. Findings from these locations led to further investigations at the site.

Hargis & Montgomery drilled nine alluvial aquifer monitoring wells and two Paluxy monitoring wells in Landfill No. 3 during 1983 and 1984 (Hargis + Associates 1985a). Multiple organic contaminants, primarily solvents, fuels, and oil and grease, were detected in water samples from all of the alluvial

aquifer wells. No analyses for contaminants in soil samples were reported. Test Holes (TH) TH-11 through TH-19 were drilled at the north end of Landfill No. 3 at the site of a suspected burn pit (Hargis & Montgomery 1983b).

Intellus Corporation (1986a) drilled one alluvial aquifer monitoring well, F-214, and two soil borings, FB-11 and FB-12, in 1986. Soil samples from F-214 and FB-12 were found to contain solvents and petroleum hydrocarbons (see Table 1-29).

Table 1-29. Previous Soil Sample Results Obtained at Landfill No. 3

Analyte	FB-12 11.0 to 11.5 feet	F-214 18.0 to 18.5 feet
Chlorobenzene	1.29 mg/kg	ND
TPH	200 mg/kg	1500 mg/kg
<i>trans</i> -1,2-Dichloroethene	0.05 mg/kg	1.95 mg/kg
PCE	ND	0.08 mg/kg
Toluene	ND	0.998 mg/kg

This investigation did not evaluate soils below the saturated zone; however, a groundwater sample collected from monitoring well F-214 was found to contain high concentrations of these contaminants (Intellus 1986a). In 1991, monitoring well F-214 had a dense non-aqueous phase liquid (DNAPL) consisting mainly of TCE and toluene, with no light non-aqueous phase liquid (LNAPL) detected.

The Radian Corporation drilled one Paluxy monitoring well, P-22U, which was found to contain low concentrations of volatile organics in a water samples taken in 1987. Subsequent analysis of samples from P-22U by Hargis + Associates detected steady levels of TCE. A sample collected in May 1990 also detected TCE (90 µg/L). Water samples from P-22U collected in December 1990 detected 48 µg/kg of TCE and 150 µg/kg of 1,2-DCE. Radian also conducted a terrain conductivity geophysical survey over Landfill No. 3 that "indicated a random pattern of anomalies that may be due to relict disposal features" (Radian 1987).

Current Investigation

The purpose of the current investigation was to better delineate the extent of contamination as outlined from the previous studies. A total of 16 soil borings were drilled during the RI/FS investigation in 1991 (see Figure 1-19). Three of these soil borings were converted to temporary monitoring wells to further delineate groundwater contamination. Soil borings were drilled to the top of the Walnut Formation with samples collected every two feet. Samples were analyzed for VOCs, semi-VOCs, TPH, and total metals. Samples collected for volatile analysis were taken from intervals within the 2-foot sample that had elevated PID readings.

VOC and Oil and Grease Soil Sample Analysis: Eighteen VOCs were detected in soil samples collected from Landfill No. 3 as shown in Table 1-30. VOCs detected were fuels-related, solvent related, and solvent degradation products. Both toluene and TCE, which were detected in the landfill, were identified as chemicals of concern in the Baseline Risk Assessment (BRA). The highest concentrations of all volatiles in Landfill No. 3 were in soil borings drilled in or adjacent to the bedrock channels. TCE was found in ten samples, with most of the locations being in the two large buried channels cut into the alluvium and bedrock. The highest concentrations of TCE and toluene were found at the bottom of soil boring/monitoring well W-130, which was drilled into a channel eroded in the Walnut Formation in the center of the landfill (see Figure 1-20). Monitoring well W-130 was found to contain DNAPL product during the groundwater investigation. TCE was also found in one sample at the north end of the landfill (SB-031) at a concentration of 120 $\mu\text{g/kg}$ (0 to 2 feet). Figure 1-23 indicates locations and concentrations of VOCs and oil and gas detected in Landfill No. 3. Several soil boring locations across the landfill were found to have low levels of VOCs, which could be expected because of the historic usage of the landfill as a liquids dump site and because of smearing when the landfill was graded.

Several isolated results of common laboratory contaminants such as acetone, methylene chloride, and 2-butanone were not shown in Figure 1-23. These substances were reported where there was agreement with adjacent samples and blanks, or where concentration levels would preclude laboratory contamination.

Semivolatile Soil Sample Analysis: Seven semivolatile compounds were detected in soil samples collected from Landfill No. 3 as shown in Table 1-31. Figure 1-25 shows locations and concentrations of semi-VOCs in Landfills No. 1 and No. 3. This figure does not show results that were qualified as estimated quantities (J) or results for bis(2-ethylhexyl)phthalate. Fluoranthene and pyrene, identified as chemicals of concern in the Plant 4 risk assessment, were both detected. The remaining semi-VOC chemicals of concern, naphthalene, 2-methylnaphthalene, and benzo(a)pyrene were tentatively identified in several samples collected at the landfill. Most of the semi-VOCs identified in Landfill No. 3 are commonly associated with coal tar or fuel oil and are probably the result of pieces of asphalt paving that were reported in several of the soil boring lithology logs. Compounds such as benzoic acid and 1,3-dichlorobenzene are common manufacturing chemicals and were detected infrequently across the landfill.

Bis(2-ethylhexyl)phthalate is a common laboratory contaminant that was reported in Landfill No. 3 in three borings—SB-063, W-129, and W-132. SB-063 had bis(2-ethylhexyl)phthalate at 1,700 $\mu\text{g/kg}$ reported in the 4- to 5.5-foot sample. This compound was also reported in the blank for that depth interval and is probably laboratory contamination. Results for W-129 reported bis(2-ethylhexyl)phthalate in several sample intervals without appearing in any blanks. Values for 4 to 5 feet, 6 to 7 feet, 8 to 9.5 feet, and 11 to 11.5 feet were 1,100, 1,300, 2,500, and 960 $\mu\text{g/kg}$, respectively. Sample results for W-132 indicated 900 $\mu\text{g/kg}$ of bis(2-ethylhexyl)phthalate at 4 to 6 feet and identified it in four other samples as estimated quantity.

Because of the types of materials encountered during drilling in the landfill, such as gravels and concrete rubble, not all samples that were attempted could be collected. In W-130 only three out of eight sample spoons had enough soil material for a semi-VOC analysis. In the event that there was not enough sample material, priority was given to collection of the VOC sample.

**Table 1-30. Summary of Landfill No. 3 Soil Samples Collected for VOC
and Oil and Grease Analysis**

Analyte	Minimum ($\mu\text{g/kg}$)	Maximum ($\mu\text{g/kg}$)	No. of Samples Analyzed	No. Above CRQL
1,1-Dichloroethene	(5)	15	57	1
1,1-Dichloroethane	(5)	17	57	1
1,1,2-Trichloroethane	(5)	24	57	1
1,2-Dichloropropane	(5)	16	57	1
1,2-Dichloroethane	(5)	1,500	57	1
1,2-Dichloroethene	(5)	14,000	56	15
2-Butanone	(10)	3,100	57	1
Acetone	(10)	38	57	3
Carbon Disulfide	(5)	15	57	1
Chlorobenzene	(5)	6	57	1
Chloroform	(5)	40	57	1
Chloromethane	(10)	85	57	2
Ethylbenzene	(5)	210	57	2
Methylene Chloride	(5)	8	57	1
Tetrachloroethene	(5)	59	57	7
Toluene	(5)	17,000	57	5
Trichloroethene	(5)	19,000	57	21
Xylene	(5)	100	57	3
Oil and Grease	(10) mg/kg	5,409 mg/kg	26	11

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene and toluene were identified in the Risk Assessment as chemicals of concern.

Table 1-31. Summary of Landfill No. 3 Soil Samples Collected for Semivolatile Analysis

Analyte	Minimum ($\mu\text{g/kg}$)	Maximum ($\mu\text{g/kg}$)	No. of Samples Analyzed	No. Above CRQL
1,3-Dichlorobenzene	(730)	1,600	31	1
Benzo(b)fluoranthene	(730)	800	31	1
Bis(2-ethylhexyl)phthalate	(750)	1,200	31	1
Chrysene	(730)	950	31	2
Fluoranthene	(730)	3,000	31	3
Phenanthrene	(730)	2,200	31	3
Pyrene	(730)	1,800	31	4

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
3) Pyrene and fluoranthene have been identified in the Baseline Risk Assessment as a chemical of concern.

Several isolated analytical results were reported for chemicals other than the asphalt-related compounds across Landfill No. 3. N-Nitrosodiphenylamine, which may be used as a fuels additive, insecticide, cutting fluid, or solvent, was detected at 1,300 $\mu\text{g/kg}$ in W-133 at a depth of 4 to 5.5 feet. This substance was not detected in other soil samples and is not considered a significant environmental hazard because of its low level of occurrence. Dibenzofuran, typically used in insecticides, was identified at 0 to 4 feet in SB-025 (88J $\mu\text{g/kg}$) and SB-032 (170J $\mu\text{g/kg}$). Pentachlorophenol, also used in insecticides, was identified at 0 to 4 feet in SB-063 (1,000J and 1,800J $\mu\text{g/kg}$ in a duplicate sample) and at 11 to 11.5 feet in W-129 (290J $\mu\text{g/kg}$).

4-Chloro-3-methylphenol, which is used as a germicide and preservative in glues or inks, was identified in W-132 at 6 to 8 feet with a value of 360J $\mu\text{g/kg}$.

Inorganic Soil Sampling Results: Nine inorganic substances were detected in soil samples collected from Landfill No. 3 as shown in Table 1-32. All five inorganic chemicals of concern were identified in Landfill No. 3 samples. Nickel was reported in only one sample from W-129 at a level slightly above the site background samples (0- to 1-foot at 20.4 mg/kg). Cadmium was reported in two samples: SB-062, 0 to 2 feet at 12.0 mg/kg, and in SB-025, 0 to 2 feet at 53.4 mg/kg. Samples that were collected for the transect of Meandering Road Creek were collected on the west edge of Landfill No. 3 and had some of the highest metals results for all soil samples collected during the field investigation (Section 1.5.4.2).

Samples collected across Landfill No. 3 indicate the irregular occurrence of the inorganics as shown by Figure 1-26. This pattern would be expected with the history of the landfill. The highest values were reported in samples collected from three soil borings: SB-025, SB-031, and SB-062. Other soil borings

Table 1-32. Summary of Landfill No. 3 Soil Samples Collected for Inorganic Analysis

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background
Antimony	(8.4)	14.2	2.2	42	2
Arsenic	(0.66)	6.8	21.6	42	0
Beryllium	(0.22)	1.3	3.6	42	0
Cadmium	(0.86)	53.4	2.8	42	2
Chromium	2.4B	72.4	196.6	42	0
Copper	(1.9)	246	90.0	42	2
Lead	2	1,250	55.1	42	5
Nickel	(5.4)	20.4	66.2	42	0
Selenium	(0.42)	(4.4)	1.4	42	0
Silver	(0.84)	1.5B	1.4	42	1
Thallium	(0.42)	0.52B	0.8	42	0
Zinc	3.8B	961	176.2	42	3

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

in Landfill No. 3 had inorganic results at background levels or only slightly elevated levels (see Appendix E of the RI). SB-025, -031, and -062 were shallow holes drilled to 3 feet, 3 feet, and 4 feet, respectively, with each hole split into two sampling intervals. The highest results were reported in the 0- to 2-foot interval for all three borings. Landfill No. 3 does not appear to be a major source area for inorganic contaminants.

TCLP Analytical Results: One soil sample collected from SB-033 at the 4.0- to 5.5-foot depth interval was split for TCLP analysis. The analysis for TCLP semivolatiles indicated all results were below detection limits. VOC analysis indicated only the presence of methylene chloride at a concentration of 33 µg/L. The analysis for TCLP metals indicated results for barium (283B µg/L) and chromium (28B µg/L). TCLP results for methylene chloride, barium, and chromium are all below the regulatory maximum concentration level.

Conclusions

A variety of soil contaminants remain in Landfill No 3. VOCs were detected in the soil at levels indicating pure product in the center of the landfill at soil boring location W-130. Some of the highest concentrations of metals in soil detected during the RI were found in soil samples collected from the western edge of the landfill near monitoring well F-214. The soil borings drilled in Landfill No. 3 show the irregular levels of contamination found across the site. The highest concentrations of soil

contaminants are found where the old drainage channels cut into the Walnut Formation were graded over. These channels have removed the Walnut Formation in Meandering Road Creek just west of the landfill and have probably exposed the Paluxy Formation. Several attempts were made to verify the presence or absence of the Walnut Formation west of monitor well F-214, but the thick sands and gravels of the creek bed did not allow a determination to be made with hand equipment.

The total amount of contaminated soil is approximately 16,000 cubic yards. Approximately 15,900 cubic yards are estimated to be contaminated with organic compounds and 3,800 cubic yards of soil are estimated to be contaminated with inorganic contaminants.

1.5.3.5 Landfill No. 4

Previous Investigations

Landfill No. 4 is located near the southwest boundary of the Plant 4 facility (Figure 1-27). This landfill occupies approximately two acres of land west of Meandering Road. Landfill No. 4 utilized a low area adjacent to Meandering Road Creek for the disposal of construction rubble from 1956 to the early 1980s. Evidence suggests that other types of wastes may have been disposed from 1966 until approximately 1973 (Radian 1987). These wastes are thought to have included small quantities of hazardous wastes such as solvents, oils, fuels, and thinners. Based on a review of aerial photographs of the landfill when it was still in use, it appears that materials other than construction rubble were deposited in the landfill. Because the landfill is located on the Meandering Road Creek flood plain, a potential exists for migration of contaminants into the surface waters of Meandering Road Creek.

Hargis & Montgomery (1983b) drilled monitoring wells HM-5 and HM-9 in the Landfill No. 4 area (Figure 1-27). Well HM-5 is located within the landfill while HM-9 was drilled adjacent to Meandering Road Creek north of Landfill No. 4. No soil samples from these wells were collected for analysis. Analysis of groundwater samples from HM-5 in 1983 indicated VOC contamination at this site (TCE - 300 µg/L, toluene - 290 µg/L, chloroform - 457 µg/L, benzene - 7 µg/L). Groundwater samples collected from HM-9 in 1983 detected TCE - 154 µg/L, tetrachloroethane - 21 µg/L, toluene - 51 µg/L, and ethylbenzene - 4 µg/L. On the basis of Installation Restoration Program (IRP) Phase II investigations (Radian 1987), a "No Further Action" remedial action alternative was recommended. This recommendation is being reconsidered based on the findings of the RI.

Current Investigation

Although this site was recommended for no further action, there were insufficient data to support this decision. The decision was based solely on groundwater monitoring data from two monitoring wells, with one (HM-5) being in the upper (upgradient) portion of the landfill and the other (HM-9) being downgradient of the landfill (Figure 1-27). The objective of the sampling at Landfill No. 4 was to evaluate whether leachate is flowing from the landfill into the adjacent soils on the flood plain of Meandering Road Creek.

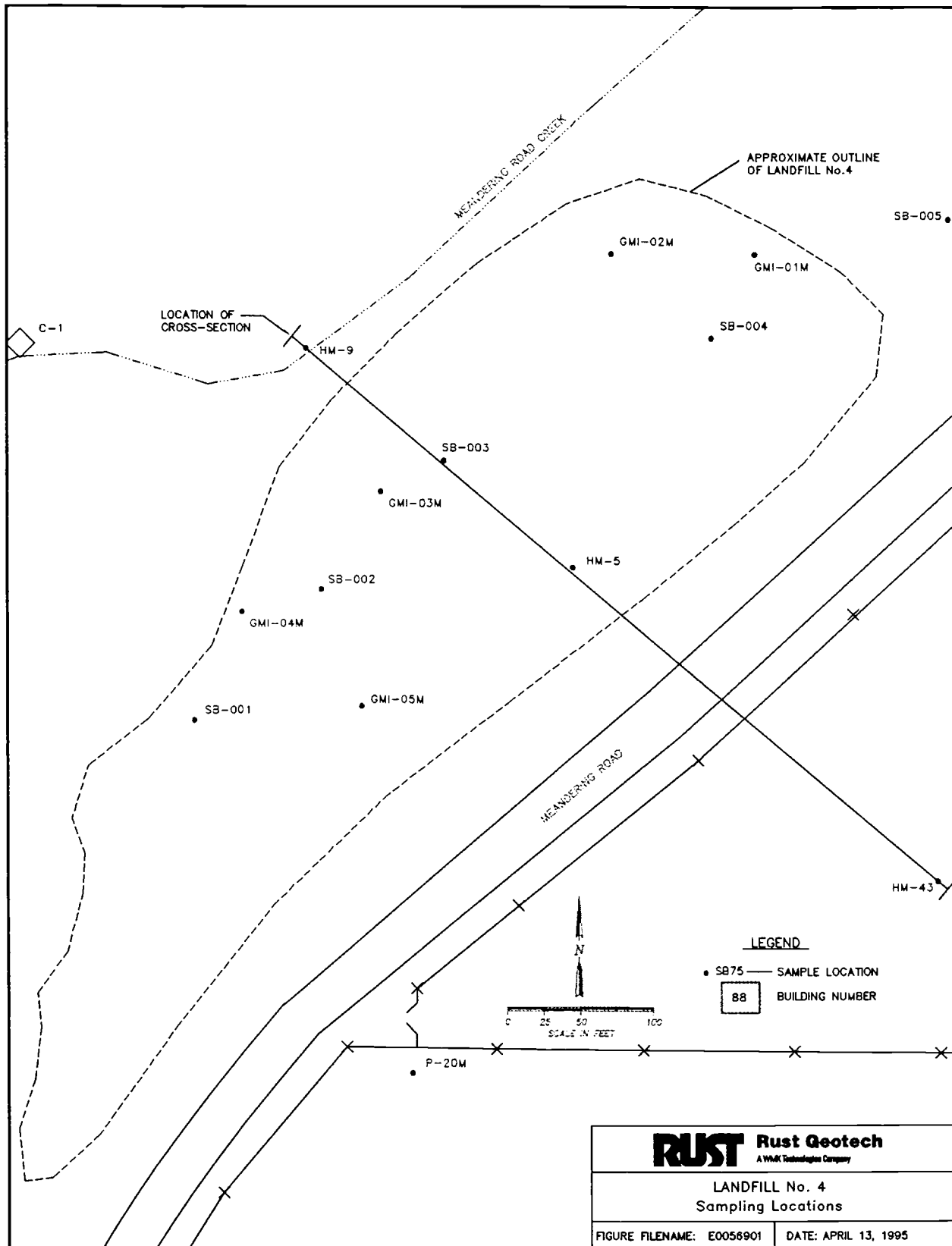


Figure 1-27. Soil Boring Locations at Landfill No. 4.

Five soil borings (SB-001, SB-002, SB-003, SB-004, and SB-005) were drilled evenly spaced on top, and along the length of Landfill No. 4, to collect representative soil samples (Figure 1-27). Soil borings were drilled to bedrock with samples collected at 2-foot intervals (i.e., 2 to 4, 4 to 6, 6 to 8, and 8 to 10 feet below the surface). With the exception of the samples for VOCs, each 2-foot interval was composited and analyzed for semi-VOCs, oil and grease, and metals. Samples for VOCs were grab samples from each 2-foot interval and were collected immediately upon opening the split barrel. Lithologic logs were completed while drilling to determine depths of fill materials and to observe any visible contamination.

Follow-Up Investigation

Geo-Marine, Inc., drilled five two-inch monitor wells (GMI-01M, -02M, -03M, -04M, and -05M) in July 1994, along the top of Landfill No. 4 for collection of soil and groundwater samples (see Figure 1-27). Each well was continuously cored to bedrock with soil samples collected at approximately 5-foot intervals. Sample depths were chosen on the basis of odor, appearance, and HNu readings. Only one well, GMI-05M, contained enough water to be developed. All samples were analyzed for VOCs, semi-VOCs, oil and grease, total petroleum hydrocarbons, and metals. Soil logs were completed for each well to identify the vertical extent of fill, correlate native soil, if any, and characterize the top of bedrock.

Summary of Soils Encountered

All five soil borings encountered Goodland Limestone and shale bedrock at total depth with the exception of SB-003 which bottomed out in a white clay. To the south of Landfill No. 4, the Goodland Limestone forms a white escarpment along the north edge of Meandering Road Creek. Subcrop of this steep erosional slope may be seen in Figure 1-28, which is a cross-section through Landfill No. 4. The cross-section runs southeast to northwest from HM-43, across Meandering Road and Landfill No. 4, to HM-9 located near Meandering Road Creek. Depicted in Figure 1-28 (vertical exaggeration 10:1) is the structural relief present on the erosional surface of the Goodland Limestone. The interbedded shale and limestone of the Goodland appear to be weathered in the area of Landfill No. 4. Underlying the Goodland is the relatively flat surface of the top of the Walnut Formation.

The unconsolidated overburden consists of fill material dumped in Landfill No. 4 and, in some places, undisturbed Quaternary alluvium. Figure 1-28 shows the variable thickness of this overburden, which is draped over the erosional scarp of the Goodland Limestone in the subsurface. SB-003 encountered about 17 feet of fill material, three feet of dark clay (some silt), and a white plastic clay in the final four feet. The section penetrated in SB-001 and SB-002 appears to be entirely fill material (15- to 23-feet thick) that rests directly on limestone bedrock of the Goodland Limestone. SB-004 penetrated 12 feet of fill material before passing through one foot of light-brown silty sand resting on bedrock of Goodland Limestone. About 18 feet of fill is present in SB-005, which is underlain by a 3-foot sequence of thinly bedded light-brown and black clays and limestone bedrock at 21-feet below surface. Composition of the fill material is highly variable, containing a trash mixture of concrete, wood, metal, and organic debris mixed with presumably locally derived clay, silt, sand, and gravel.

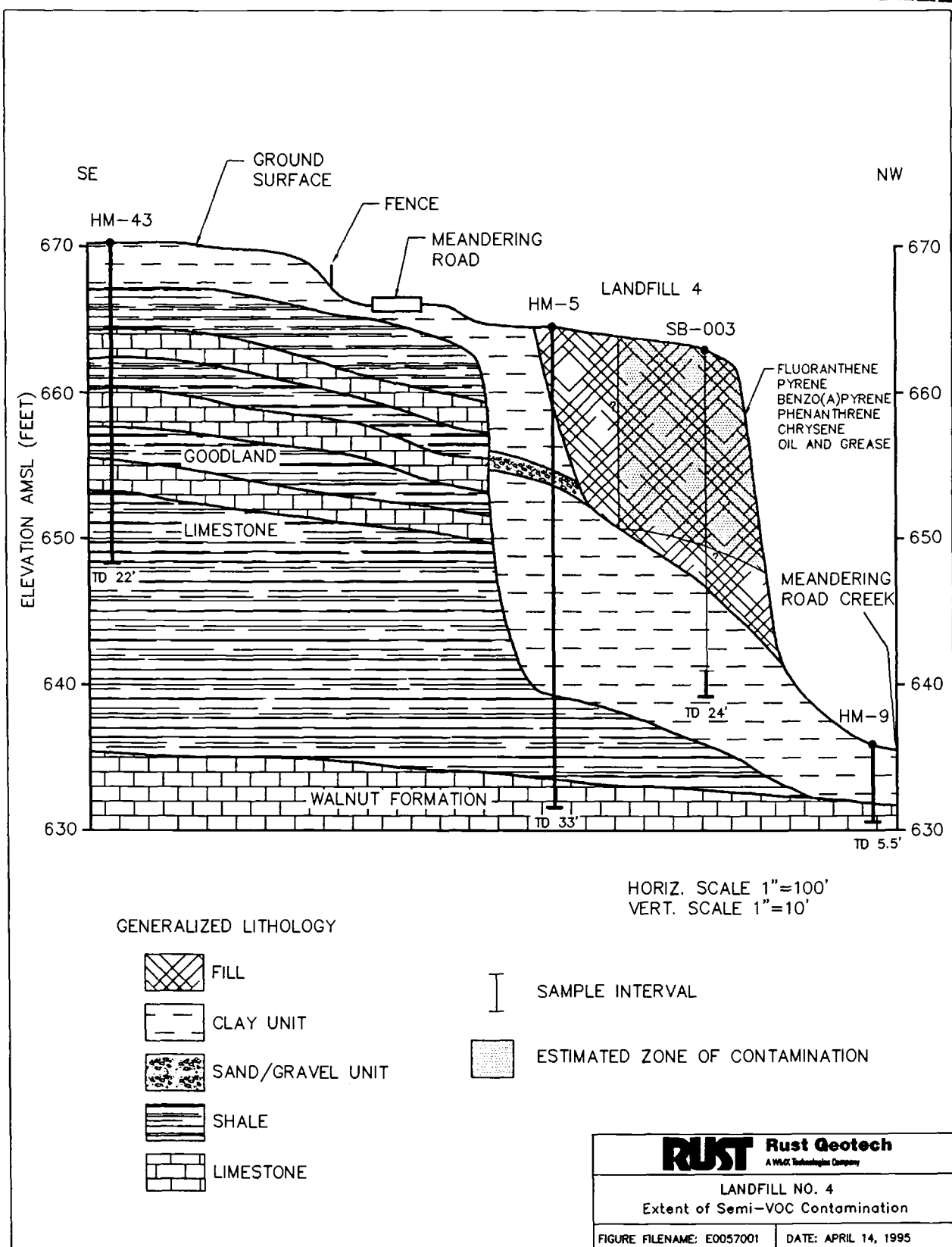


Figure 1-28. Cross Sectional View Across Landfill No. 4.

Results of the Current Investigation

Landfill No. 4 was previously recommended for no further action based on the analytical results of groundwater samples from HM-5 and HM-9. The recent soil sampling and analysis for boreholes SB-001 through SB-005 found contamination of VOCs, semi-VOCs, and metals at the landfill. The data are summarized in Tables 1-33, 1-34, and 1-35. Detailed data are presented in Appendix E of the RI.

Table 1-33. Summary of VOC and Oil and Grease Analytical Results for Soil Samples Obtained from Landfill No. 4

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Acetone	(10)	89	42	20
2-Butanone	(10)	20	42	4
Tetrachloroethene	(5)	12	42	3
Trichloroethene	(5)	27	42	6
Oil and Grease	11 mg/kg	6,020 mg/kg	32	19

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene was identified in the Risk Assessment as a chemical of concern.

Numerous VOCs and semi-VOCs were detected in soils from SB-001 and SB-003 (see Table 1-33 and Table 1-34). TCE was found in SB-001 at sample depths of 4 feet to 14 feet, with a maximum concentration of 27 µg/kg. Numerous additional contaminants are present in soils from SB-001 and include fluoranthene, pyrene, benzo(a)pyrene, phenanthrene, chrysene, benzo(a)anthracene, bis(2-ethylhexyl)phthalate, and oil and grease. Soils from SB-003 were found to contain the same suite of semi-VOCs as reported in SB-001. Significant concentrations of these semi-VOCs were found in SB-003 from 4 feet below surface to 12.5 feet (see Figure 1-28). The organic contaminant distribution is illustrated in Figure 1-29.

Anomalously high concentrations of all five metals of concern were found in the analyses of soil from SB-001 (see Table 1-35 and the Appendix E of the RI). Zinc was detected at more than 60 times the upper range for background soils of the western United States in the soil sample from 6 to 8 feet. Cadmium (31 times), chromium (16 times), and copper (19 times) all exceeded background in soils from SB-001. The depth range of metals contamination in SB-001 is 4 to 14 feet. Lead and silver also were significantly higher than western United States soils. Above-background concentrations of metals were also present in the top four feet of fill in SB-002 (see Appendix E of the RI). The extent of metals contamination is shown in Figure 1-30.

Table 1-34. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from Landfill No. 4

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Acenaphthene	(710)	1,200	70	2
Acenaphthylene	(710)	800	70	1
Anthracene	(710)	3,700	70	3
Benzo(a)anthracene	(710)	8,800	69	8
Benzo(a)pyrene	(710)	7,200	70	8
Benzo(b)fluoranthene	(710)	8,600	70	8
Benzo(g,h,i)perylene	(710)	7,000	70	6
Benzo(k)fluoranthene	(710)	5,100	70	7
bis(2-ethylhexyl)phthalate	(710)	6,000	70	8
Chrysene	(710)	9,300	70	8
Dibenz(a,h)anthracene	(710)	1,600	70	1
Dibenzofuran	(710)	1,100	70	1
Fluoranthene	(710)	12,000	70	9
Fluorene	(710)	1,500	70	2
Indeno(1,2,3-cd)pyrene	(710)	4,100	70	5
Naphthalene	(710)	1,200	70	1
Phenanthrene	(710)	11,000	70	7
Pyrene	(710)	7,600	70	8

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
3) Pyrene, benzo(a)pyrene, naphthalene, and fluoranthene were identified in the Risk Assessment as chemicals of concern.

Table 1-35. Summary of Inorganic Analytical Results for Soil Samples Obtained from Landfill No. 4

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for the Western USA
Antimony	(8)	(11)	2.2	32	1
Arsenic	2.4	12.4	21.6	32	0
Beryllium	(0.23)	1.1	3.6	32	0
Cadmium	(0.8)	87.3	2.8	32	8
Chromium	5.5	3,170	196.6	32	4
Copper	3.2B	1,690	90.0	32	5
Lead	4.3	1,560	55.1	32	9
Nickel	5.5B	202	66.2	32	4
Selenium	(0.4)	(4.8)	1.4	32	0
Silver	(0.8)	21.4	1.4	32	6
Thallium	(0.4)	(0.55)	0.8	32	0
Zinc	10	12,200	176.2	32	6

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.
4) Upper background from range in Soils of Western USA, Shacklette and Boerngen, 1984.
5) Upper limits for cadmium, silver, and thallium, are estimated from the four Plant 4 background samples.

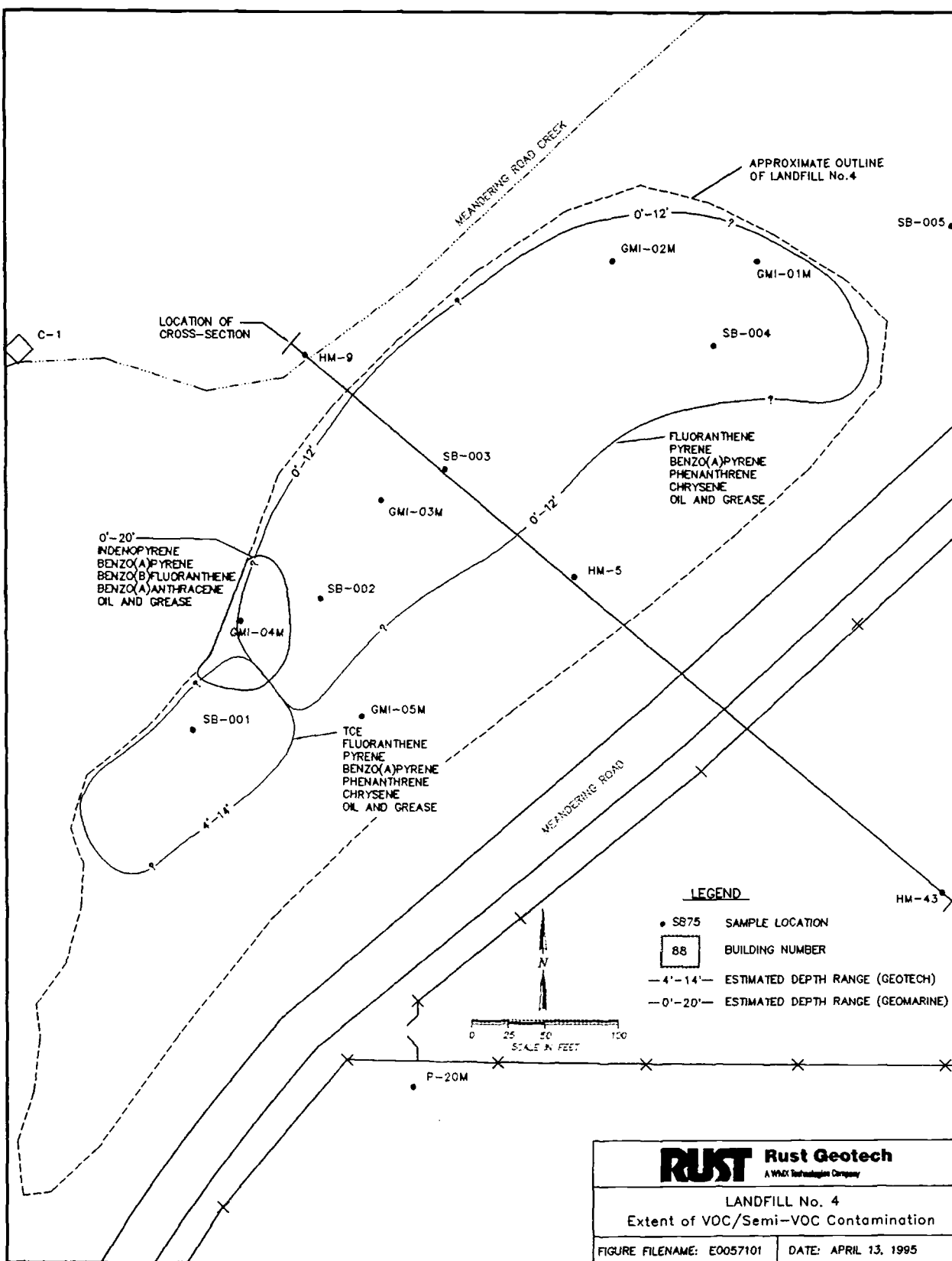


Figure 1-29. Extent of VOCs and Semi-VOCs Detected at Landfill No. 4.

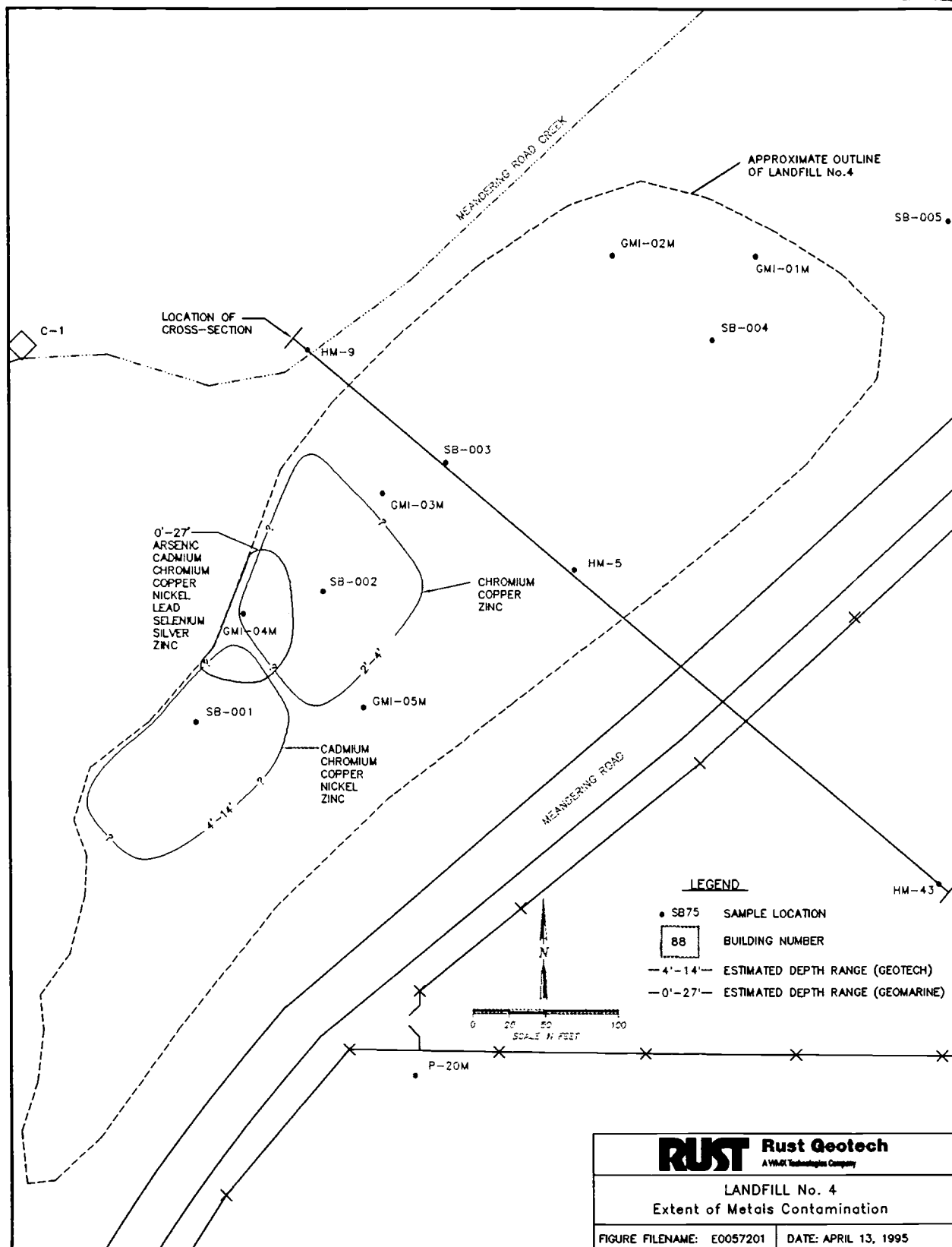


Figure 1-30. Extent of Metals Detected at Landfill No. 4.

Analytical results from the Geo-Marine investigation indicate contamination of VOCs, semi-VOCs, oil and grease, metals, and total petroleum hydrocarbons at all locations. Data are summarized in Tables 1-33A, 1-34A, and 1-35A. Detailed data are presented in Appendix E.

Table 1-33A Summary of VOC and Oil and Grease Analytical Results for Geo-Marine Soil Samples

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed
Acetone	1,100	32,000	25
2-Butanone	(1,000)	3,800	25
Carbon Disulfide	(500)	1,400	25
Chloroethane	(500)	540	25
Chloromethane	500	2,700	25
Methylene Chloride	2,600	12,000	25
Oil and Grease	(10) mg/kg	1,100 mg/kg	25

Notes: 1) Concentrations in parentheses indicate the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Table 1-34A Summary of Semi-VOC Analytical Results for Geo-Marine Soil Samples

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed
Anthracene	(330)	540	25
Benzo(a)anthracene	(330)	12,000	25
Benzo(a)pyrene	(330)	13,000	25
Benzo(b)fluoranthene	(330)	21,000	25
Benzo(g,h,i)perylene	(330)	4,800	25
Benzo(k)fluoranthene	(330)	10,000	25
bis(2-ethylhexyl)phthalate	(330)	15,000	25
Chrysene	(330)	14,000	25
Din-n-butylphthalate	(330)	750	25
Dibenz(a,h)anthracene	(330)	460	25
Fluoranthene	(330)	21,000	25
Fluorene	290	(330)	25

**Table 1-34A Summary of Semi-VOC Analytical Results for Geo-Marine Soil Samples
(continued)**

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed
Indeno(1,2,3-cd)pyrene	(330)	5,200	25
Phenanthrene	(330)	12,000	25
Pyrene	(330)	33,000	25

Notes: 1) Concentrations in parentheses indicate the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, phenanthrene, and pyrene were identified in the Risk Assessment as chemicals of concern.

Results for VOC and semi-VOC analyses indicate soils from GMI-04M are the most contaminated. Soils from GMI-04M had concentrations above detection limits for 14 semi-VOC and four VOC analytes to a depth of 20 feet. Maximum concentrations for phenanthrene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene were detected in GMI-04M at a depth of 15- to 20-feet. Fluorene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, benzo(g,h,i)perylene and 2-butanone were detected only in GMI-04M. Semi-VOCs were detected at or below 1 mg/kg in all other borings. Acetone and methylene chloride were detected in all samples. Oil and grease were detected in every well, but not in all samples from each well, with highest concentrations at the near surface in GMI-01M, and at 15- to 20-feet in GMI-04M.

Table 1-35A Summary of Inorganic Analytical Results for Geo-Marine Soil Samples

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit ³ mg/kg	No. of Samples Analyzed
Antimony	1.2	40	2.2	25
Arsenic	5.9	170	21.6	25
Cadmium	(1.0)	160	2.8	25
Chromium	5.1	570	196.6	25
Copper	(1.0)	3,200	90.0	25
Cyanide	(1.0)	1.6	NA ⁴	25
Lead	2.1	460	55.1	25
Nickel	2.7	260	66.2	25
Selenium	(1.0)	38	1.4	25
Silver	(0.5)	10	1.4	25
Zinc	4.6	4,200	176.2	25

Notes: 1) Concentrations in parentheses indicate the compound was not detected at the reported value.
 2) Cadmium, chromium, copper, lead, nickel, and zinc were identified in the Risk Assessment as chemicals of concern.
 3) Upper background from range in Soils of Western USA, Shacklette and Boerngen, 1984.
 4) Not Available

Maximum concentrations for all metals detected were from GMI-04M soils (see Table 1-35A and Appendix E). Three of the five chemicals of concern (cadmium, copper, and zinc) had anomalously high concentrations in the soils from GMI-04M. Cadmium was detected at more than 50 times the upper range for background soils of the Western USA in the 0-5 foot sample. Copper (36 times), selenium (28 times), and zinc (24 times) all exceeded background in soils from GMI-04M.

Soils from the four other Geo-Marine wells also contained concentrations greater than background for antimony and arsenic. Chromium was not detected above background at any of the other wells. Zinc, copper, and cadmium were detected at concentrations greater than background at all locations except GMI-05M. Cyanide was detected only at GMI-04M. Silver and lead also were detected at GMI-01M and GMI-02M in concentrations greater than background. Well GMI-03M was the only location to exceed the background concentration for nickel. Selenium was detected at GMI-02M in concentrations greater than background.

Conclusions - Current Investigation

The heterogenous composition of Landfill No. 4 makes characterization of the soil contamination difficult. Figures 1-29 and 1-30 show the interpreted extent of significant contamination for VOCs and semi-VOCs, and metals, respectively. Horizontal limits of contamination were constrained by distances to adjacent boreholes and by the landfill boundaries. Vertical extent of contamination determinations were complicated by poor sample recovery caused by concrete rubble, boulders, or trash in the landfill. In borehole intervals with no recovery, contamination was assumed if adjacent samples were contaminated. Significant concentrations of contaminants of concern are present in SB-001, SB-002, and SB-003. This evidence proves that other wastes in addition to construction rubble were deposited in Landfill No. 4.

The volume of contaminated material was estimated using the areal extent of the envelopes shown in Figures 1-29 and 1-30 and thickness of contamination (depth range). The estimated volume of VOC and semi-VOC contamination is approximately 32,000 cubic yards. Metals contamination was found in SB-001 (same area and volume as calculated for VOCs and semi-VOCs) and SB-002. The estimated volume of metals contaminated soil is 5,300 cubic yards, which is included in the volume of VOC contamination. The combined total volume of soil contaminated with VOCs, semi-VOCs, and metals for Landfill No. 4 is 32,000 cubic yards.

The most significant contamination at Landfill No. 4 is lead and polynuclear aromatic compounds (benzo(a)pyrene, benzo(b)fluoranthene, and benzo(a)anthracene). The probability of migration of contaminants into the groundwater system or the surface waters of Meandering Road Creek has not been determined.

Conclusions - Follow-Up Investigation

The Geo-Marine data could not be validated because only a portion of the quality control data was available. This data indicated results were not within prescribed limits for quality control parameters for both metals and organic analyses. Nevertheless, areas of contamination and contaminants were substantially consistent with previous investigations, although contaminants were found deeper than previously reported. At GMI-04M, both organics and metals concentrations were elevated at 20 feet. The most significant contamination is lead and polynuclear aromatic compounds.

1.5.3.6 Fire Department Training Area No. 2 (FDTA-2)

Summary of Previous Investigations

FDTA-2 was a 50-foot-diameter earthen ring located north of Landfill No. 1 (Figure 1-31) in the west parking lot. This site was used for fire training exercises from 1955 to 1956. Exercises were held twice a year with approximately 250 gallons of waste oils and fuels used for each exercise. It is suspected that disposal of oils and fuels and uncontrolled burns may have been more frequent (CH2M Hill 1984). The site is currently located under the pavement of the west parking lot.

Hargis + Associates (1985a) drilled monitoring wells HM-49, HM-51, HM-65, HM-66, and HM-76 near the suspected location of FDTA-2 (see Figure 1-31). Well HM-51 is believed to be located within FDTA-2 based on chemical analyses of groundwater samples. Hargis + Associates believes lateral contaminant migration from FDTA-2 would be limited by the low transmissivity of sediments encountered at the site.

One test boring (FB-7) and one monitoring well (F-213) were installed by Intellus during a 1986 field investigation. Analysis of soil samples from both drill holes detected total petroleum hydrocarbons (200 mg/kg) from the 3- to 3.5-foot depth, but none were detected in the lower soil sample (7.5 feet to 8 feet). VOCs were not detected in soils from F-213 or FB-7. Soil samples were not analyzed for metals. The Intellus study revealed shallow soil contamination (3 feet to 4 feet) surrounding HM-51. Intellus estimated the volume of contaminated soil to range from 3,500 to 4,500 cubic yards.

Radian performed a terrain conductivity survey in 1985 to determine the presence and configuration of FDTA-2. The geophysical survey detected an anomalous zone in the general area of the site that is interpreted to reflect shallow soil contamination and/or a chemical reaction between contamination and subsurface materials (Radian 1987).

Previous investigations found soil contaminated with petroleum hydrocarbons in soil boring FB-7 and monitoring well F-213. Groundwater contamination in HM-51 may be from the disposal of oils and fuels in FDTA-2.

Current Investigation

Four soil borings (SB-68 to SB-71) were drilled surrounding monitoring well HM-51, which is located near what is believed to be the approximate center of FDTA-2 (see Figure 1-31). The borings were located 25 feet north, south, east, and west of existing well HM-51. Soil samples were collected from the borings to determine the vertical extent of contamination and provide preliminary information on the horizontal extent of contamination. The soil samples were collected from the surface to bedrock in 2-foot intervals. Grab samples for VOCs were collected from each interval, and the remaining material was composited and analyzed for semi-VOCs, petroleum hydrocarbons, and metals. Lithology logs were completed to determine any visual contamination and examine the depth of any excavations.

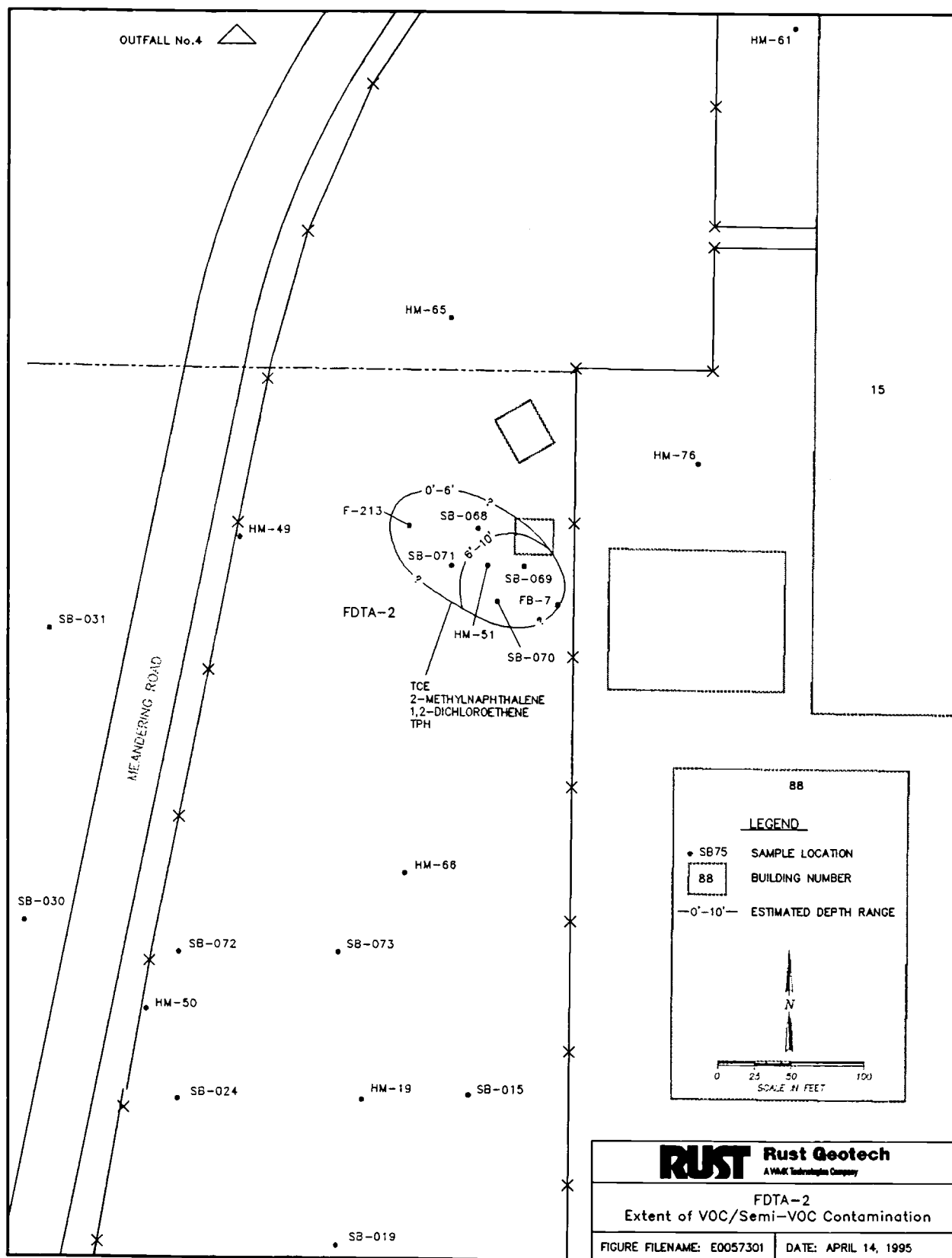


Figure 1-31. Extent of VOCs, Semi-VOCs, and TPH Detected at FDTA-2.

Groundwater samples were to be collected from inside the hollow stem augers following soil sampling; however, there was no water in the borings at the time of drilling. Each soil boring was left open for several hours and, in at least one case, overnight to allow water to accumulate, but no measurable water was evident.

In a variance from the SAP four additional soil borings that were to have been drilled outward from the initial soil borings when contamination was detected, were not drilled. In the vadose zone, contamination associated with a fire training area will be very localized and tend to migrate vertically downward to the water table. TPH contamination was detected in the shallow soils at FDTA-2 and below two-feet only in relatively low concentrations (less than 100 mg/kg) except for SB-069 where the TPH concentrations dropped below the detection limit at two feet and remained low until 10 to 12 feet where the TPH level rose to 234 mg/kg. This is believed to indicate the presence of groundwater contamination that may not be associated with FDTA-2 but may come from the abandoned JP-4 pipe line south of this site. Additional borings were not drilled because they would have been too far from FDTA-2 to detect the localized contamination. Additionally, nearby downgradient monitoring wells did not indicate elevated levels of contamination related to a fire training area.

Summary of Soils

Soil borings SB-068, SB-069, SB-070, SB-071 were drilled to bedrock with a hollow stem auger to depths of 10 feet, 12 feet, 12 feet, and 11 feet below surface, respectively. Borehole information and lithologic descriptions are contained on the borehole logsheets (see Appendix A-2 of the RI).

Underneath a thin asphalt cover, each borehole encountered 2 feet to 3.5 feet of black, organic-rich clayey-silt and clayey-sand. The remainder of Quaternary alluvium consists primarily of olive to yellowish-brown silty clay (sandy in part) with some thin interbeds of limestone and limestone gravels. Light gray limestone and shale bedrock of the Walnut Formation was reached at 10 to 11 feet below surface in the four boreholes. HM-51, reportedly drilled in the center of FDTA-2, encountered the Walnut Formation at 12 feet below surface.

Results of the Investigation

Analyses of the Geotech soil samples detected the presence of significant concentrations of VOCs, semi-VOCs, TPH, and metals (see Table 1-36, Table 1-37, Table 1-38, and Appendix E of the RI).

Analysis of the shallow sample (0 feet to 2 feet) from SB-069 detected 1,300 $\mu\text{g/kg}$ of 2-methylnaphthalene, a common JP-4 compound (see Table 1-37). TPH were detected at shallow depths in all four boreholes as well as FB-7 and F-213. The maximum concentration of petroleum hydrocarbons is 917 mg/kg (see Table 1-36). Hydrocarbons were also detected at 8 feet to 10 feet in SB-069. This isolated detection at depth may be attributed to groundwater contamination. Average depth to the water table is about six feet in the FDTA-2 area. TCE (20 $\mu\text{g/kg}$) was found in the upper two feet of SB-70. Figure 1-31 shows the extent of contamination of VOCs, semi-VOCs, and hydrocarbons.

Table 1-36. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from FDТА-2

Analyte	Minimum μg/kg	Maximum μg/kg	No. of Samples Analyzed	No. Above CRQL
4-Methyl-2-pentanone	(11)	16	24	1
1,2-Dichloroethene	(6)	9	24	2
Acetone	(11)	210	24	12
2-Butanone	(11)	140	24	10
Trichloroethene	(6)	20	24	1
Total Petroleum Hydrocarbons	(10) mg/kg	917 mg/kg	23	13

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene was identified in the Baseline Risk Assessment as a chemical of concern.

Table 1-37. Summary of Semi-VOC Analytical Results for Soil Samples Obtained From FDТА-2

Analyte	Minimum μg/kg	Maximum μg/kg	No. of Samples Analyzed	No. Above CRQL
2-Methylnaphthalene	(750)	1300	29	2

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

The concentration of all metals of concern was significantly more than background in the first two feet of soil in SB-068 (Table 1-38). The maximum level for copper was more than 90 times the upper background range for soil of the western United States in the shallow soil sample from SB-068. Other metals of concern were elevated 3 to 25 times background in this borehole. Silver, lead, and antimony were also elevated in one or two boreholes. The areal extent of metals contamination defined by SB-068 is illustrated in Figure 1-32.

Conclusions

Analyses of soils from the recently drilled boreholes confirmed the presence of petroleum hydrocarbons at shallow depths in all four boreholes. TCE was detected in the 0- to 2-foot interval in SB-070 and 2-methylnaphthalene was found in soil from the surface interval in SB-069. The areal extent of VOCs, semi-VOCs, and hydrocarbon contamination is shown in Figure 1-31. The estimated volume of soil contaminated with organics was computed using the product of the area and thickness, and equals 1,350 cubic yards.

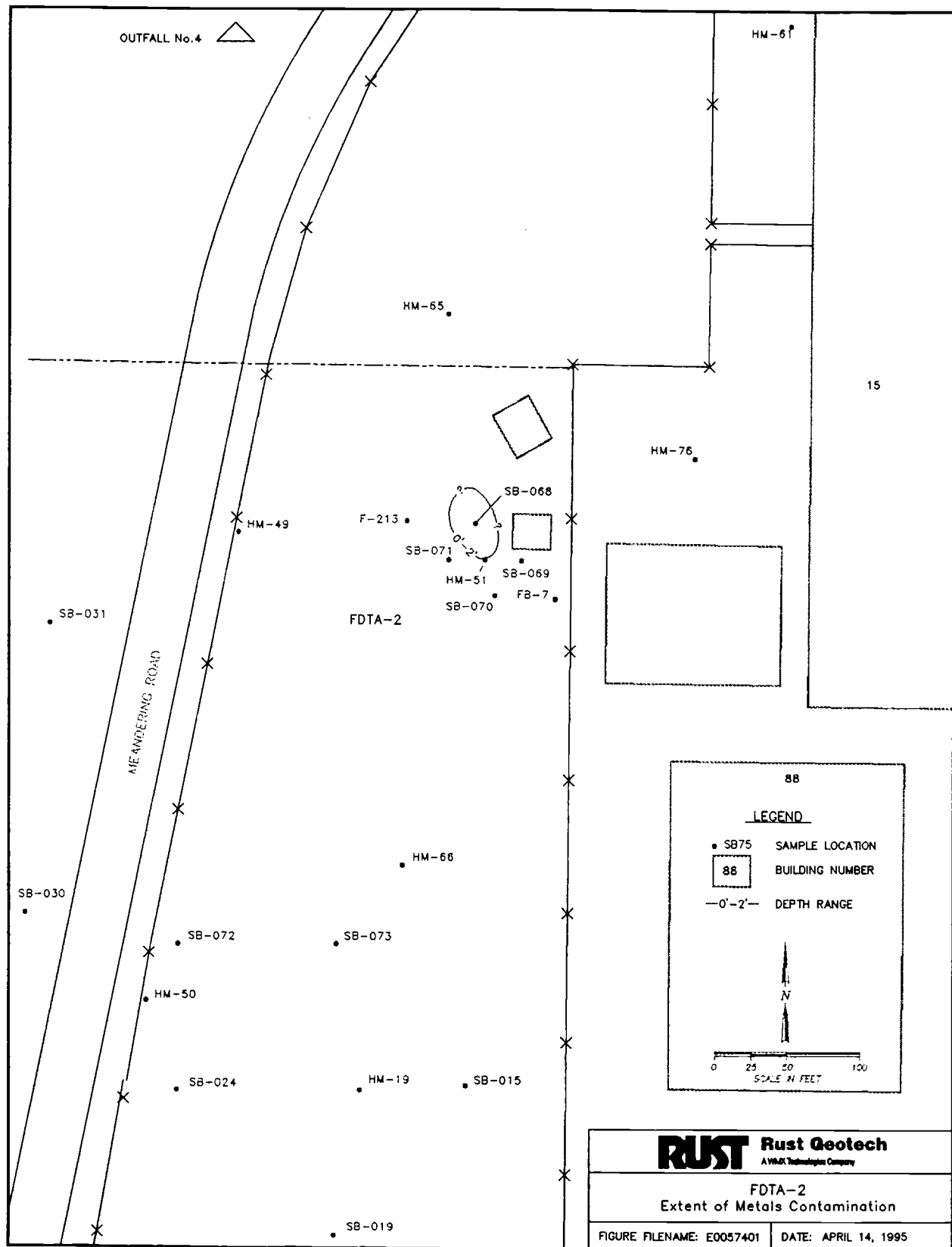


Figure 1-32. Extent of Metals Detected at FDTA-2.

Table 1-38. Summary of Inorganic Analytical Results for Soil Samples Obtained from FDTA-2

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background d ⁴
Antimony	(9.1)	14.8	2.2	23	1
Arsenic	1.6B	13.3	21.6	23	0
Beryllium	0.3B	1.5	3.6	23	0
Cadmium	(0.92)	69.8	2.8	23	4
Chromium	8.8	549	196.6	23	1
Copper	(1.8)	8060	90.0	23	1
Lead	3.2	84.6	55.1	23	2
Nickel	(5.7)	413	66.2	23	1
Selenium	(0.46)	(2.3)	1.4	23	0
Silver	(0.91)	8.7	1.4	23	1
Thallium	(0.46)	0.6B	0.8	23	0
Zinc	5.4	2060	176.2	23	1

- Notes:
- 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 - 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 - 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Base Risk Assessment as chemicals of concern.
 - 4) Upper background from range in Soils of Western USA, Shacklette and Boerngen, 1984.

The shallow sample from SB-068 contained high levels of metals of concern. About 90 cubic yards of soil contaminated with metals is estimated to surround borehole SB-068.

1.5.3.7 Fire Department Training Area No. 5 (FDTA-5)

Summary of Previous Investigations

FDTA-5, located near the Die Yard area south of Facilities Building No. 12 (Figure 1-33), consisted of a shallow pit about 35 feet by 45 feet in size, which received waste fuels, oils, and unspecified chemicals that were burned for fire extinguisher training exercises during the mid-1960s. It has since been graded and paved.

In 1983, Hargis + Associates drilled monitoring well HM-25 in the vicinity of FDTA-5 (Figure 1-33). No analyses for soil samples were reported for this well. Laboratory analyses of groundwater samples from HM-25 indicated the presence of benzene, chlorobenzene, ethylbenzene, trichloroethene, 1,2-*trans*-dichloroethene, dichlorobenzenes, oil and grease, and fuel hydrocarbons. Results of chemical analyses

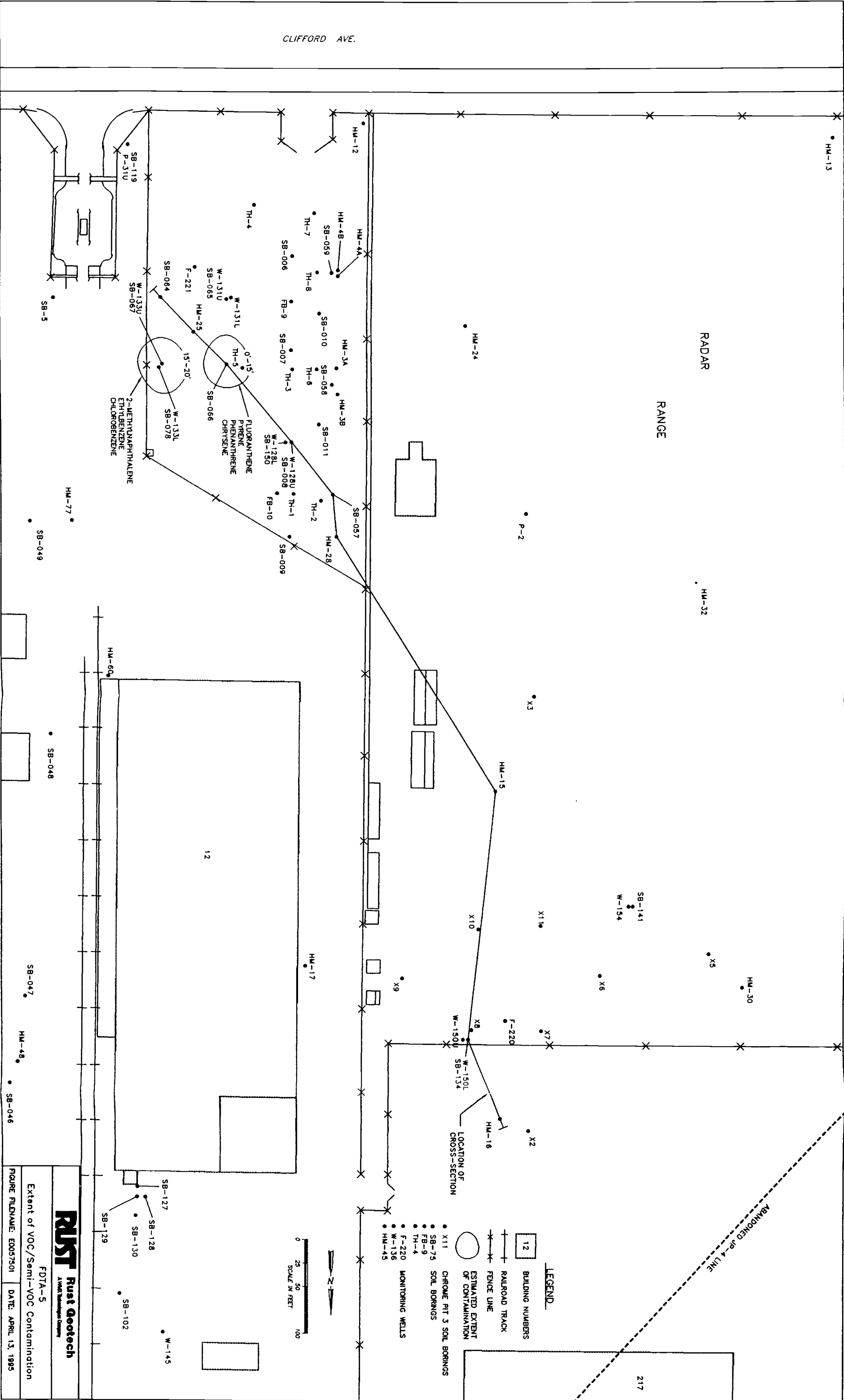


Figure 1-33. Extent of VOCs and Semi-VOCs Detected at FDA-5.

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and water elevation data suggest that upper-zone groundwater contamination at HM-25 is primarily the result of historic waste disposal practices at FDTA-5, with possible contribution from the Die Yard Chemical Pits (DYCP) (Hargis + Associates 1985).

Intellus (1986) installed monitoring well F-221 adjacent to FDTA-5 (Figure 1-33). Field organic vapor readings indicate levels of VOCs from 1 to 5 ppm in the soils from the surface to a depth of 11 feet. From a depth of 11 to 19 feet readings indicate levels 1 to 70 ppm of VOCs. Laboratory analyses of the soils did not indicate any VOCs or TPH. Trace metals were found at levels typical of native soils (Intellus 1986). Laboratory analysis of the water sample from F-221 did not detect the presence of any volatiles. A concentration of 103 ppm of TPH was found in the water sample.

Soil boring SB-5 was drilled by Radian in 1986, east of FDTA-5 (Figure 1-33). Based on color, odor, and organic vapor readings, selected soil samples were submitted for laboratory analyses. No significant concentrations of contaminants in the soil samples were found by the analyses. However, analyses of groundwater samples from monitoring wells in the area indicate the presence of trace metals and organic contaminants in excess of Federal MCL criteria.

Analytical results from soil samples collected from F-221 and SB-5 indicate that the shallow soils do not contain significant concentrations of contaminants. Groundwater samples, however, contained concentrations of VOCs, semi-VOCs, and fuel related hydrocarbons.

Current Investigation

Five soil borings (SB-064, SB-065, SB-066, SB-067, and SB-078) were drilled at FDTA-5 to help define the lateral extent of soil contamination. The soil borings are located 50 feet northeast, northwest, southeast, and southwest of monitoring well HM-25, which is located near the reported center of the training area (Figure 1-33). The borings were drilled to the water table or bedrock and soil samples were collected in 5-foot intervals. Samples for VOC analysis were grab samples taken from each 5-foot interval. The remaining samples were composite samples representing the entire 5-foot interval. The composite samples were analyzed for semi-VOCs, oil and grease, and metals.

Summary of Soils Encountered

The five soil borings penetrated a variable and unknown thickness of concrete and fill material followed by 12 to 15 feet of silty clay with some thin interbeds of sand and limestone gravel. The coarser grained basal sequence consists of sand and gravel units interbedded with some clay stringers with a total thickness of 1 to 4 feet in the FDTA-5 area. Calcareous shale bedrock (Goodland Limestone) was found in SB-066 and SB-078 at depths of 15 and 25 feet, respectively. Detailed lithologies and well summary information may be found on the Borehole Lithologic Log Sheets (see Appendix A-2 of the RI).

Figure 1-34 depicts the generalized subsurface geology interpreted for the subsurface of the FDTA-5, Die Yard, and Chrome Pit No. 3 areas. FDTA-5 is located at the southeast end of the cross section and appears to be situated in a saddle between two bedrock highs composed of limestone and shale of the Goodland Limestone. A basal sequence of sand and gravel thins over the bedrock high to the northeast. Figure 1-35 is a structure contour map of competent bedrock that shows the configuration of these bedrock highs. An interpretation of the subcrop pattern of the Goodland Limestone and Walnut Formation is also presented in Figure 1-35.

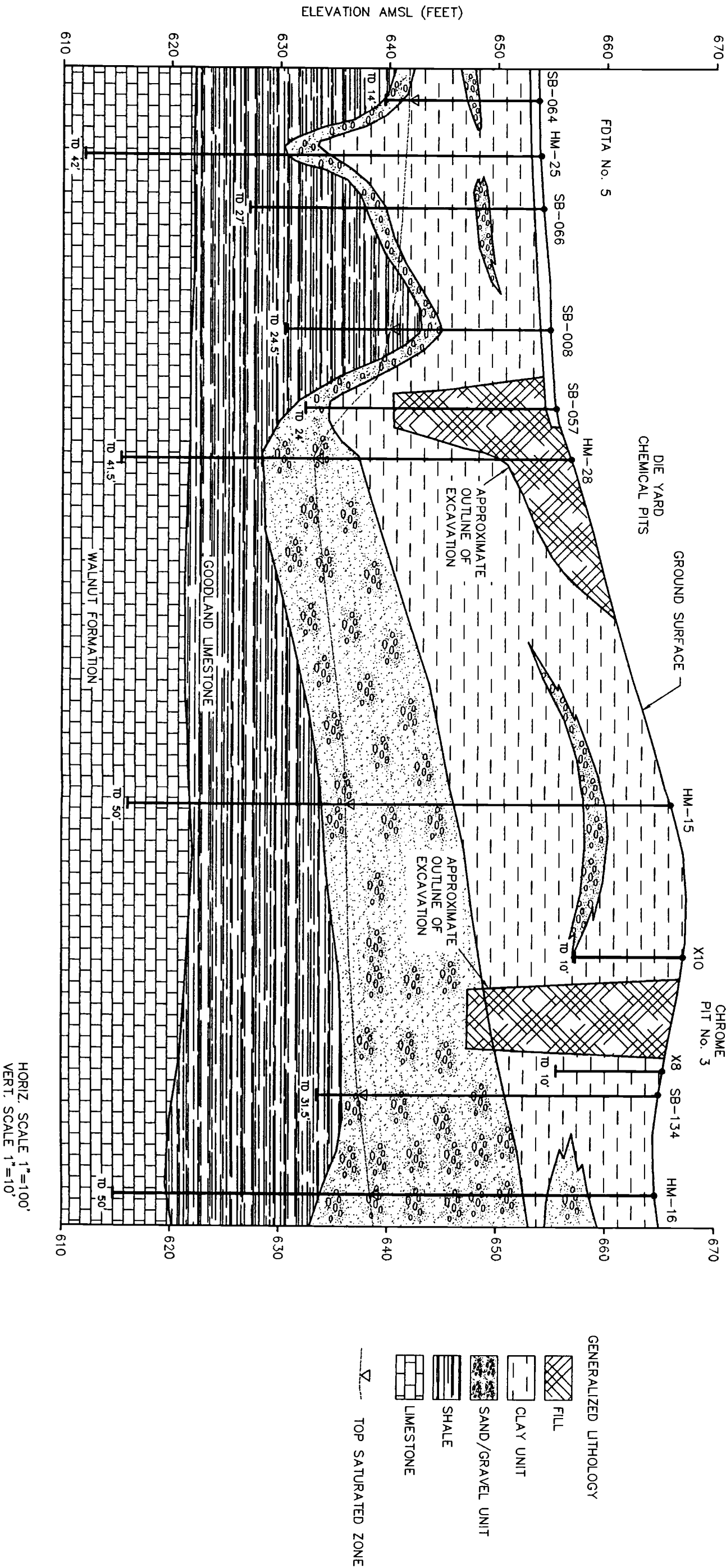


Figure 1-34. Cross Section of Generalized Subsurface Geology at FDTA-5.

RUST Rust Geotech A Rust Technology Company	
FDTA-5 Geologic Cross Section	
FIGURE FILENAME: E0037801	DATE: APRIL 14, 1995



Figure 1-35. Structure Contour Map Showing Subcrop of Competent Bedrock at FDTA-5.

Results of the Investigation

Laboratory analysis of the soil samples revealed the presence of three semi-VOC chemicals of concern in significant concentrations (see Table 1-39 and the Appendix E of the RI). Fluoranthene (2,000 $\mu\text{g/kg}$) and pyrene (1,600 $\mu\text{g/kg}$) were found in the upper 5 feet of SB-066, and 2-methylnaphthalene (1,900 to 2,000 $\mu\text{g/kg}$) was detected in the 18- to 20-foot and 15- to 20-foot intervals of SB-067 and SB-078, respectively.

Table 1-39. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from FDТА-5

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
2-Methylnaphthalene	(730)	2,000	20	2
Benzo(b)fluoranthene	(730)	920	20	1
Bis(2-ethylhexyl)phthalate	(730)	1,300	20	2
Chrysene	(730)	940	20	1
Fluoranthene	(730)	2,000	20	2
Phenanthrene	(730)	1,600	20	1
Pyrene	(730)	1,600	20	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, and 2-methylnaphthalene were identified in the Baseline Risk Assessment as chemicals of concern.

A summary of laboratory results for analysis of VOCs and oil and grease is included in Table 1-40. Ethylbenzene, 92 $\mu\text{g/kg}$, was detected in the 18- to 20-foot interval of SB-067 and 69 $\mu\text{g/kg}$ in the 15- to 20-foot interval of SB-078. Chlorobenzene (80 $\mu\text{g/kg}$) was also found in SB-067 while oil and grease (154 mg/kg) was present in the corresponding interval of SB-078. The interpreted areal distribution of VOC/semi-VOC contaminants is shown in Figure 1-33.

Table 1-40. Summary of VOC and Oil and Grease Analytical Results for Soil Samples Obtained from FDТА-5

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
2-Butanone	(11)	47	19	3
Acetone	(12)	930	19	17
Chlorobenzene	(5)	80	19	1
Ethylbenzene	(5)	140	19	3
Oil and Grease	(10) (mg/kg)	154 (mg/kg)	19	3

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Table 1-41. Summary of Inorganic Analytical Results for Soil Samples Obtained From FDТА-5

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for Western USA
Antimony	(8.8)	(9.9)	2.2	19	0
Arsenic	2.5	8.7	21.6	19	0
Beryllium	0.36B	0.69B	3.6	19	0
Cadmium	(0.88)	2	2.8	19	0
Chromium	6.3	33.3	196.6	19	0
Copper	4.7B	8.5	90.0	19	0
Lead	4.5	15.4	55.1	19	0
Nickel	(5.5)	14.2	66.2	19	0
Selenium	(0.46)	(2.2)	1.4	19	0
Silver	(0.88)	(0.99)	1.4	19	0
Thallium	(0.44)	(0.49)	0.8	19	0
Zinc	11.6	28.5	176.2	19	0

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

Concentrations of metals in the FDТА-5 samples were found to be within the range for background soils for the western United States (see Table 1-41).

TCLP Analytical Results

The EPA TCLP was used for analysis of VOCs, semi-VOCs, and inorganic constituents for sample SB-067-04, obtained 18- to 20-feet below ground level. Analysis of the liquid TCLP extract indicated that barium, at a concentration of 538B $\mu\text{g/L}$, was the only inorganic analyte detected. This value is below the 100,000 $\mu\text{g/L}$ regulatory level. VOCs or semi-VOCs were not detected in the sample.

Conclusions

Laboratory analyses of the soil samples from the FDТА-5 area indicate the presence of semi-VOCs and VOCs. The shallow contamination in SB-066 of fluoranthene and pyrene is likely the result of fire training activities at FDТА-5 or possibly asphalt related. The chemicals 2-methylnaphthalene and ethylbenzene, found in SB-067 and SB-078, are common JP-4 compounds that may have migrated vertically from FDТА-5. The sample depth interval of 15 to 20 feet is close to the water table depth of 23 feet that was encountered in SB-078. It is possible that this deeper contamination is related to groundwater.

The estimated extent of contamination is shown in Figure 1-33. The volume of contaminated material was estimated by using the areal extent and the thickness of contamination (depth range). A total volume of approximately 900 cubic yards is estimated for the two areas sampled by SB-066, SB-067, and SB-078.

1.5.3.8 Fire Department Training Area No. 6 (FDTA-6)

Summary of Previous Investigations

FDTA-6 was the primary fire department training area at Plant 4 from the late 1950s to 1980 (CH2M Hill 1984). It was located on the northwestern side of Plant 4 adjacent to Meandering Road and Lake Worth (Figure 1-36). FDTA-6 consisted of a 50-foot-diameter gravel-lined ring that was approximately 2-feet deep and surrounded by an earthen berm (Hargis & Montgomery 1983). The training area was used from the late 1950's to 1980 for periodic training exercises that used approximately 250 gallons of waste fuels and oils per exercise. Before 1970, training exercises were conducted twice a year and after 1970 exercises were conducted at monthly intervals (Radian 1987). The IRP Phase I investigation (CH2M Hill 1984) indicated that unknown quantities of fuels and oils were likely deposited in FDTA-6 between training exercises.

In 1982, Hargis & Montgomery collected soil samples from TH-26, which was drilled to a depth of 6 feet in the fire-training burn pit (Figure 1-36). The sample from 2 to 3 feet was submitted for chemical analysis. Methylene chloride (217 $\mu\text{g/kg}$), di-n-butylphthalate (170 $\mu\text{g/kg}$), and oil and grease (0.379 mg/kg) were detected in soils from TH-26.

Interim remedial action was performed at FDTA-6 in 1982 and 1983 when oil-and-fuel contaminated soils were removed and hauled to an approved hazardous waste landfill. Although most of the contamination may have been removed, there were insufficient data to verify that remaining contaminants did not pose a potential risk to the environment or human health.

In 1986, Intellus Corporation drilled test borings FB-1, FB-2, and FB-3 (Figure 1-36) at the reported location of FDTA-6. Laboratory analysis of the soil samples failed to identify any contaminants. As shown in Figure 1-36, these borings may not have been properly located.

The IRP Phase II investigation was carried out by Radian Corporation in 1985 and 1986. Activities included hand augering and collection of soil samples from six holes in May, 1986 from 6 to 18 inches deep: HA-1, HA-2, HA-3, HA-4, HA-5, and HA-6 (Figure 1-36). Results of the analyses are presented in Radian 1987. Five of six soil samples show evidence of residual contamination associated with past activities at FDTA-6. Significant concentrations of hydrocarbon fuels (14,000 mg/kg), oil and grease (13,000 mg/kg), TCE (21 $\mu\text{g/kg}$), naphthalene (2,300 $\mu\text{g/kg}$), and phenanthrene (8,300 $\mu\text{g/kg}$) were detected in the soil samples.

Analytical results of previous investigations indicate that the soils around FDTA-6 are contaminated with VOCs, semi-VOCs, fuel hydrocarbons, and oil and grease. The following contaminants have been identified at FDTA-6: fuel-related hydrocarbons, oil and grease, TCE, naphthalene, and phenanthrene. Data from these investigations were evaluated, but as the exact location of the borings was not known, the data were not used to define extent of contamination. The three FB-series borings drilled by Intellus (Figure 1-36) were used to demonstrate contamination was not spreading.

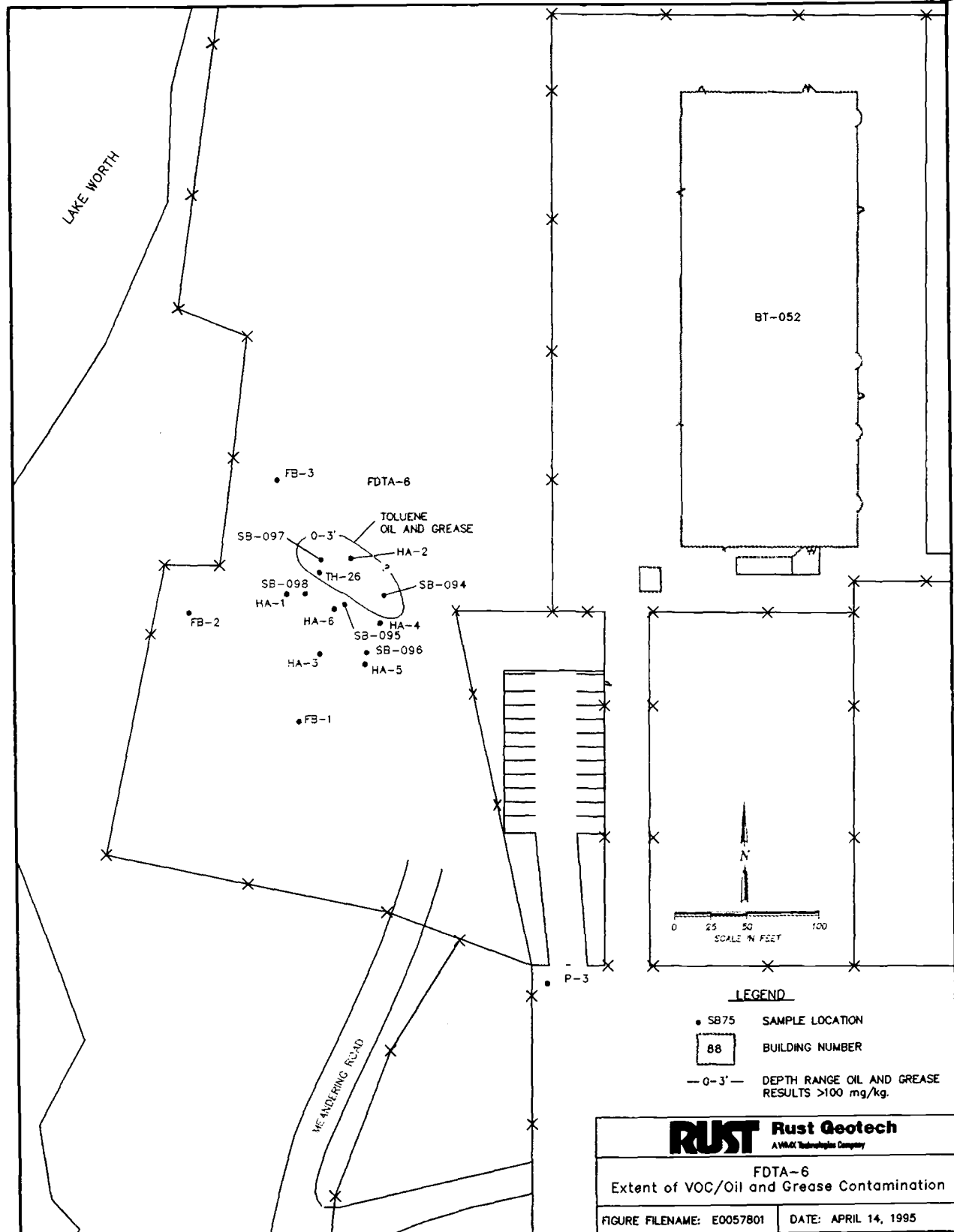


Figure 1-36. Extent of Toluene and Oil and Grease Detected at FDTA-6.

Current Investigation: During the current investigation it was noted that the area of FDTA-6 was used as a temporary storage area for fill dirt. This fill material was piled over an area covering part of the former FDTA-6 site and the area just to the south. This material was removed by May 1991.

On the basis of a review of information concerning the interim remedial action, five soil borings (SB-094, SB-095, SB-096, SB-097, and SB-098) were drilled inside the center and around the perimeter of the excavated portion of FDTA-6 (see Figure 1-36). The borings were drilled to the top of the Walnut Formation and a single soil sample was collected; VOCs were sampled immediately as grab samples, and the remaining sample material was composited over the entire length of the boring. The composited soils were analyzed for semi-VOCs, oil and grease, and metals. A single boring (SB-095) drilled in the approximate center of the excavated portion of FDTA-6 was sampled and analyzed using the same protocol specified for the other borings at FDTA-6 to determine if contamination exists below the excavated zone.

Summary of Soils Encountered

Bedrock is very shallow in the area of FDTA-6. The Walnut Formation was reached at 2 to 2.5 feet in all five Geotech boreholes. The Walnut Formation consists of gray shale and fossiliferous limestone which is mantled by a thin veneer of soft weathered bedrock. The unconsolidated material overlying bedrock is primarily fill which varies from roadbase sand and gravel at the surface to a mottled clay with some limestone fragments underneath. No visual evidence of contamination, such as oil-stained soil was observed at the site.

Results of the Investigation

Toluene was the only chemical of concern identified by laboratory analyses (see Table 1-42 and Appendix E of the RI). A toluene concentration of 11 $\mu\text{g/kg}$ was detected in the soil sample from SB-094. Oil and grease was found in four of five boreholes with a maximum concentration of 2,300 mg/kg in SB-097. An outline of the extent of contamination of toluene and oil and grease is shown in Figure 1-36.

Table 1-42. Summary of VOC Analytical Results for Soil Samples Obtained From FDTA-6

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
Acetone	(11)	11	5	1
Toluene	(5)	11	5	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 1) Toluene was identified in the Baseline Risk Assessment as a chemical of concern.

The concentrations of metals detected are within the expected range of background soils for the area (see Table 1-43).

Table 1-43. Summary of Inorganic Analytical Results for Soil Samples Obtained from FDТА-6

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (ug/kg)	No. of Samples Analyze d	No. Above Natural Background for the Western USA ⁴
Antimony	(9.1)	(9.7)	2.2	5	0
Arsenic	1.7B	5.7	21.6	5	0
Beryllium	0.59B	0.95B	3.6	5	0
Cadmium	1.2	2.8	2.8	5	0
Chromium	11.5	18	196.6	5	0
Copper	4.5B	9.8	90.0	5	0
Lead	8.2	31	55.1	5	0
Nickel	6.9B	12.5	66.2	5	0
Selenium	(0.46)	(2.3)	1.4	5	0
Silver	(0.91)	(0.97)	1.4	5	0
Thallium	(0.45)	(0.48)	0.8	5	0
Zinc	19.3	40.5	176.2	5	0

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.
4) Upper background from range in Soils of Western USA, Shacklette and Boerngen, 1984.

Conclusions

The previous interim remedial action and various earth moving activities in the FDТА-6 area resulted in either removal or redistribution of contaminated soil. Relatively low levels and limited extent of toluene and oil and grease were found in two boreholes.

1.5.3.9 Chrome Pit No. 3

Summary of Previous Investigations

Chrome Pit No. 3, located on the Radar Range west of Facilities Building No. 12 (see Figure 1-37), was used from 1957 to 1973 for the disposal of chromate, barium-chromate sludge, dilute metal solutions, and drums of unidentified liquids. The pit measured 66 feet wide by 165 feet long by 15-feet deep (Hargis + Associates 1985).

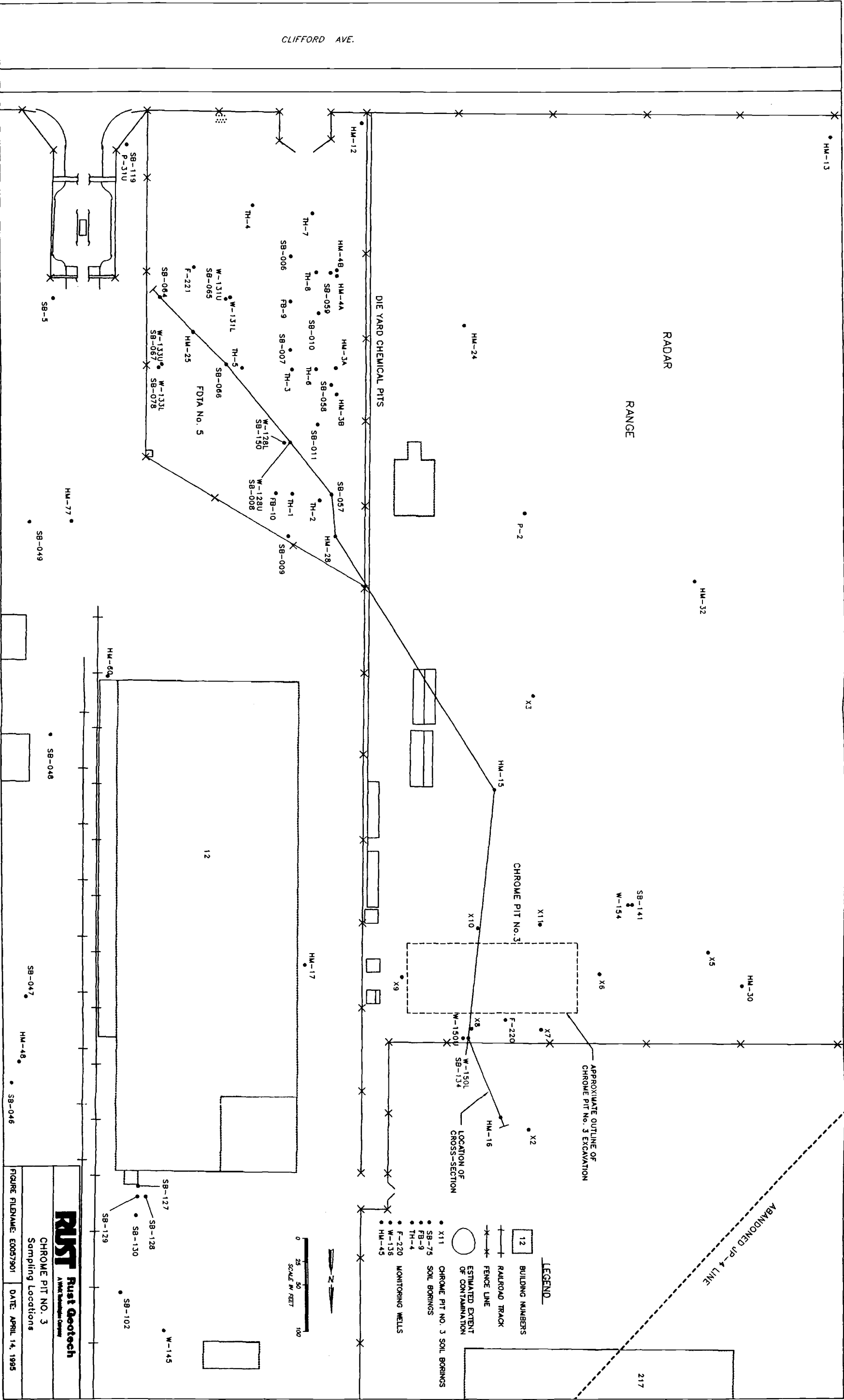


Figure 1-37. Sample Locations at Chrome Pit No. 3.

Soil samples were collected by Hargis & Montgomery (1983) during the drilling of monitoring well HM-1, whose location is shown in Plate 3. Four of 21 samples collected, ranging in depth from 9 to 27 feet, were analyzed for trace metals, cyanide, and organics. The principal contaminants and maximum concentrations reported are: TCE (172,500 $\mu\text{g/kg}$), toluene (55 $\mu\text{g/kg}$), xylene (1,073 $\mu\text{g/kg}$), benzene (139 $\mu\text{g/kg}$), diethyl phthalate (328,399 $\mu\text{g/kg}$), di-n-butyl phthalate (16,650 $\mu\text{g/kg}$), methylene chloride (44,420 $\mu\text{g/kg}$), cyanide (0.11 $\mu\text{g/g}$), chromium (0.84 mg/L), copper (0.33 mg/L), nickel (0.93 mg/L), and zinc (0.99 mg/L) [units provided by Hargis & Montgomery (1983)].

Hargis + Associates (1985) drilled monitoring wells HM-15, HM-16, HM-17, and HM-30 in the area surrounding Chrome Pit No. 3 (see Figure 1-37). From December 1983 through January 1984, approximately 8,900 cubic yards of contaminated soil was excavated and removed from the chrome pit as an interim remedial action. The approximate outline of the excavation is illustrated in Figure 1-37. Analytical results of samples collected during the excavation indicate that the greatest concentrations of contaminants were removed (CH2M Hill 1984). However, some contaminants may remain in the soils and groundwater adjacent to the excavated portion of the pit. Monitoring well HM-1 was destroyed during the excavation.

Intellus (1986) drilled a test boring (FB-8, Plate 3), which has been destroyed, and monitoring well (F-220) at Chrome Pit No. 3. Organic vapor readings of soil samples did not indicate the presence of VOCs to a depth of 13 and 23 feet for FB-8 and F-220, respectively. VOCs were indicated from 13 to 26 feet in FB-8 and from 23 to 29 feet in F-220. Laboratory analyses of soil samples failed to detect the presence of any VOCs. Analysis of the water sample from F-220 identified levels of TCE and other VOCs. The levels of metals found were within the mean range typical for native soils (Intellus 1986).

Versar, under contract to UNC Geotech, collected 12 soil samples (X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, and X99) from 11 locations in December 1989 around the perimeter of the former excavation and the additional area to be occupied by a proposed chemical waste treatment process building (see Figure 1-37). Sample X99 was a duplicate/blank sample collected at boring X11. A single composite sample was taken from each of the 11 borings. Borings X1 and X4 (shown in Plate 3) are located west of boring X5 and just off Figure 1-37. Lithologic logs for each of the 11 shallow borings (10 feet or less) are in Appendix K of the RI. As each sample was removed from the borehole and the split-spoon was opened, a portable organic vapor analyzer was used to determine the presence of VOCs. All readings indicated that the soil samples did not contain elevated levels of volatile organics. Each sample was analyzed for volatiles, total extractable halogens, and Contract Laboratory Program (CLP) metals (including hexavalent chromium). Results of laboratory analyses indicated that none of the samples contained high concentrations of toxic organics or inorganics. The sample from boring X10 had 72.5 mg/kg total extractable halogens.

Although remedial action was performed at Chrome Pit No. 3, the amount of samples collected within the excavated area was not sufficient to determine that the site no longer poses a threat to human health or the environment.

Current Investigation: During the current investigation, two soil borings were drilled and completed as monitoring wells (SB-134/W-150 and SB-141/W-154). The two wells were installed as upgradient and downgradient wells to help determine the source of contaminants in the groundwater in the Chrome Pit No. 3 area. One soil sample was collected from the depth interval of 26 to 29 feet in SB-134. The water table was found at 28 feet. The single sample was analyzed for VOCs, semi-VOCs, and metals.

Summary of Soils Encountered

Boreholes SB-134 and SB-141 were drilled northeast and southwest, respectively, of the former Chrome Pit No. 3 site. Competent shale bedrock of the Goodland Limestone was found 29 feet below the surface in SB-134 and at 32 feet below the surface in SB-141. Figure 1-38 shows the surface of competent bedrock in the area of Chrome Pit No. 3 and the Die Yard areas. Chrome Pit No. 3 appears to be located over a broad, subtle, bedrock high that plunges gently to the southwest in the direction of SB-141. The subtle relief on this bedrock high is also evident on the cross section presented in Figure 1-39. Location of the cross section is shown in Figure 1-37.

The generalized stratigraphy of the Quaternary sediments in the Chrome Pit No. 3 area is shown in Figure 1-39 and the Borehole Lithologic Log Sheets in Appendix A-2 of the RI. The soils may be described as follows: approximately 14 feet of silty clay with occasional sand stringers and traces of sand and limestone fragments, which is underlain by 15 feet of clayey sand interbedded with limestone gravels and some silty clay. This unconsolidated alluvium rests on a thin veneer of weathered shaley material of the Goodland Limestone, which mantles the bedrock high present in the area.

Figure 1-39 shows the outline of fill material resulting from excavation of Chrome Pit No. 3. The approximate boundaries of the excavation were derived by using the surface area (Versar 1990) and calculating the average depth reached by removal of the reported 8,900 cubic yards of material.

Results of the Investigation

Results of laboratory analysis of the single sample (26 to 29 feet) from SB-134 are in Table 1-44, Table 1-45, and the Appendix E of the RI. TCE was detected at a concentration of 12,000 $\mu\text{g}/\text{kg}$ in the soil sample. Figure 1-39 shows the location of the sample interval with TCE contamination with respect to the water table. The sample interval (26 to 29 feet) spans the depth to water level (28 feet) found in the borehole. The TCE contamination is most likely related to groundwater. Acetone and 2-butanone were also detected in the soil sample. These two contaminants are likely to be laboratory contaminants. Metals were found to be within the range for background soils of the western United States.

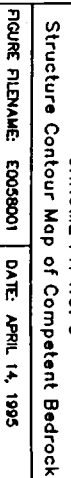


Figure 1-38. Structure Contour Map Showing Subcrop of Competent Bedrock at Chrome Pit No. 3.

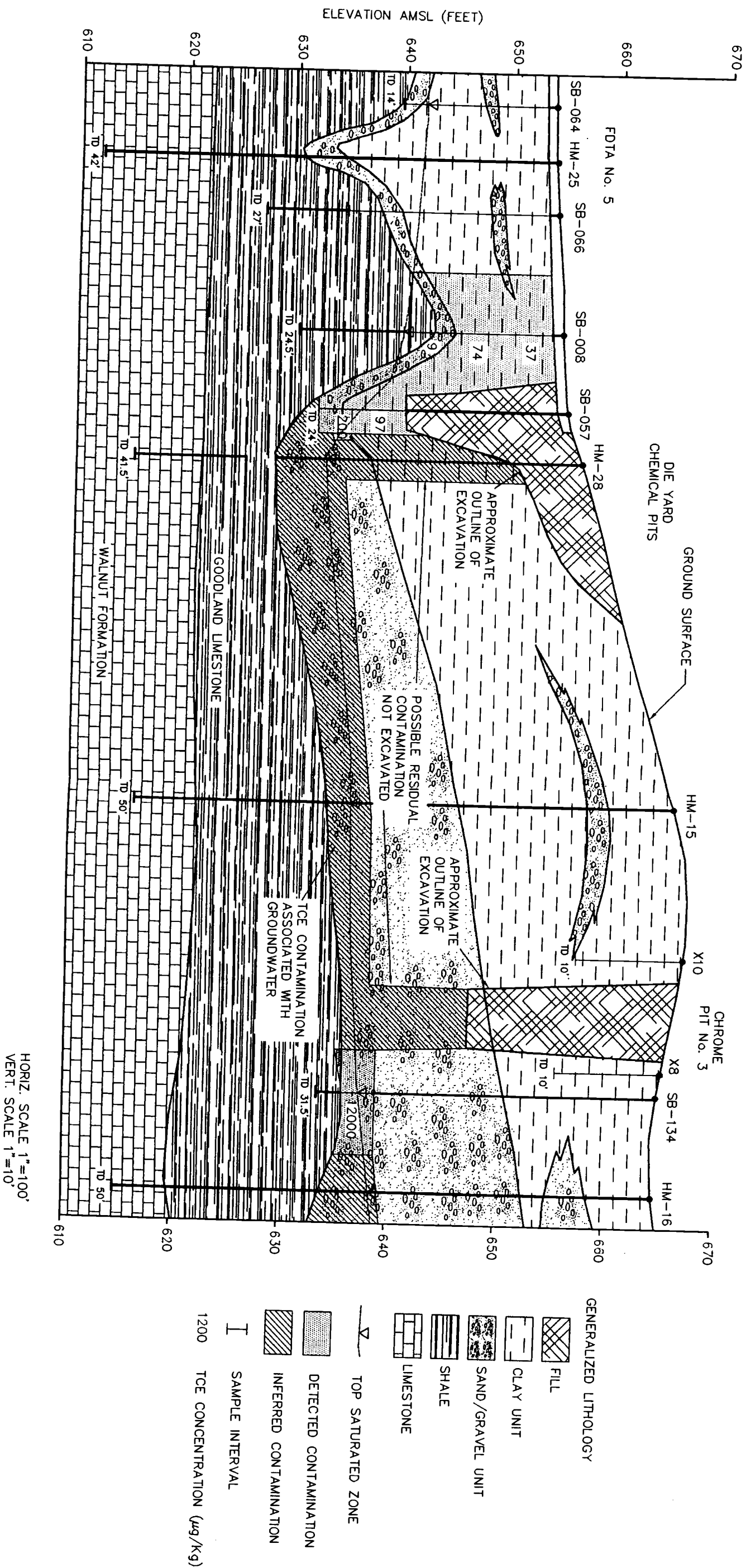


Figure 1-39. Cross Section of Generalized Subsurface Geology at DYCP and Chrome Pit No. 3.

RUST Rust Geotech A Rust Technology Company	
CHROME PIT No. 3	
TCE Contamination	
FIGURE FILENAME: E0038101	DATE: APRIL 14, 1995

Table 1-44. Summary of VOC Analytical Results for the Soil Sample Obtained from Chrome Pit No. 3

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Acetone	2,300	2,300	1	1
2-Butanone	3,900	3,900	1	1
Trichloroethene	12,000	12,000	1	1

- Notes: 1) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 2) Trichloroethene was identified in the Baseline Risk Assessment as a chemical of concern.

Table 1-45. Summary of Inorganic Analytical Results for the Soil Sample Obtained from Chrome Pit No. 3

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for Western USA
Antimony	(9.1)	(9.1)	2.2	1	0
Arsenic	7.8	7.8	21.6	1	0
Beryllium	0.49B	0.49B	3.6	1	0
Cadmium	0.94B	0.94B	2.8	1	0
Chromium	24.5	24.5	196.6	1	0
Copper	6.5	6.5	90.0	1	0
Lead	4.6	4.6	55.1	1	0
Nickel	(5.7)	(5.7)	66.2	1	0
Selenium	(0.45)	(0.45)	1.4	1	0
Silver	(0.91)	(0.91)	1.4	1	0
Thallium	(0.45)	(0.45)	0.8	1	0
Zinc	17.3	17.3	176.2	1	0

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.
 4) Cyanide was detected in the SB-134 sample at a concentration of 0.05 mg/kg.

Conclusions

The concentration of TCE detected in the soil sample from SB-134 is likely to be associated with groundwater. However, field screening of soils found above the sample depth in SB-134 showed 9 to 23 ppm VOC from the 20- to 26-foot depth. Further inspection of Figure 1-39 shows the location of the inferred excavation with respect to the closest sample intervals of SB-134, X8, and X10. The average depth of the excavation is estimated to be 18 feet. HM-1 previously was located within Chrome Pit No. 3 and subsequently destroyed with the excavation of contaminated soil. Significant contamination was detected in soils from 22 to 27 feet in HM-1, including TCE at a concentration of 63,500 $\mu\text{g/kg}$ at 22 to 23 feet in depth. This previously reported TCE contamination is below the estimated base of the excavation and is above the water table at 22 to 23 feet. The peripheral sampling performed by Versar was limited to 10 feet total depth and is unlikely to intersect any residual contamination that may have migrated vertically downward from Chrome Pit No. 3.

It is possible that residual contamination exists below the excavation. Additional sampling below the excavation will be necessary to verify this contamination.

1.5.3.10 Die Yard Chemical Pits (DYCP)

Summary of Previous Investigations

DYCP site is located east of the Radar Range and south of Facilities Building No. 12 (Figure 1-40). Three pits with approximate dimensions of 20 by 90 feet were constructed in 1956 and used for the disposal of chromate sludges, metal solutions, and other chemical wastes. In 1962, the site was graded and the entire DYCP was paved (second shift parking lot, Lot No. 9). On the basis of the IRP Phase I investigation, it is suspected that contaminated soils from the pits may have been spread around the DYCP area during the grading activities. The site of the original pits was excavated and 1,100 cubic yards of contaminated soil were removed and transported to an approved hazardous waste landfill for disposal (CH2M Hill 1984). Confirmation sampling was not conducted to verify that the area was adequately remediated.

Test Holes TH-1 through TH-8 were drilled by Hargis & Montgomery in December 1982 to locate the chemical waste pits in the DYCP (Figure 1-40). No analyses of soil samples are reported for these test holes, and only one groundwater sample was collected and analyzed for VOCs and trace metals from TH-3. The results from this sample are reported in Hargis & Montgomery (1983) as follows: 34 $\mu\text{g/L}$ benzene, 157 $\mu\text{g/L}$ chloroform, 12,000 $\mu\text{g/L}$ 1,1-DCE, 20,000 $\mu\text{g/L}$ methylene chloride, 4,000 $\mu\text{g/L}$ TCE, 0.90 mg/L chromium, 0.059 mg/L iron, 0.011 mg/L manganese, and 0.210 mg/L strontium.

In December 1982, Hargis & Montgomery drilled monitoring wells HM-3A and HM-4A to determine the residual concentrations of contaminants at the site. Lithologic logs for the test holes (TH-1 through TH-8) and monitoring wells HM-3A and HM-4A are in Appendix K of the RI. At well HM-3A, soil samples collected from depth intervals of 3 to 4 feet, 7 to 8 feet, 9 to 10 feet, and 14 to 15 feet were analyzed for trace metals, cyanide, and organics. Equivalent analyses were performed on HM-4A samples from depth intervals of 3 to 4 feet, 7 to 8 feet, 11 to 12 feet, 14 to 15 feet, and 16 to 25 feet. Results of the analyses are reported in Hargis & Montgomery (1983). The principal contaminants and maximum reported concentrations are as follows: TCE (11,000 $\mu\text{g/kg}$), toluene (20,000 $\mu\text{g/kg}$),

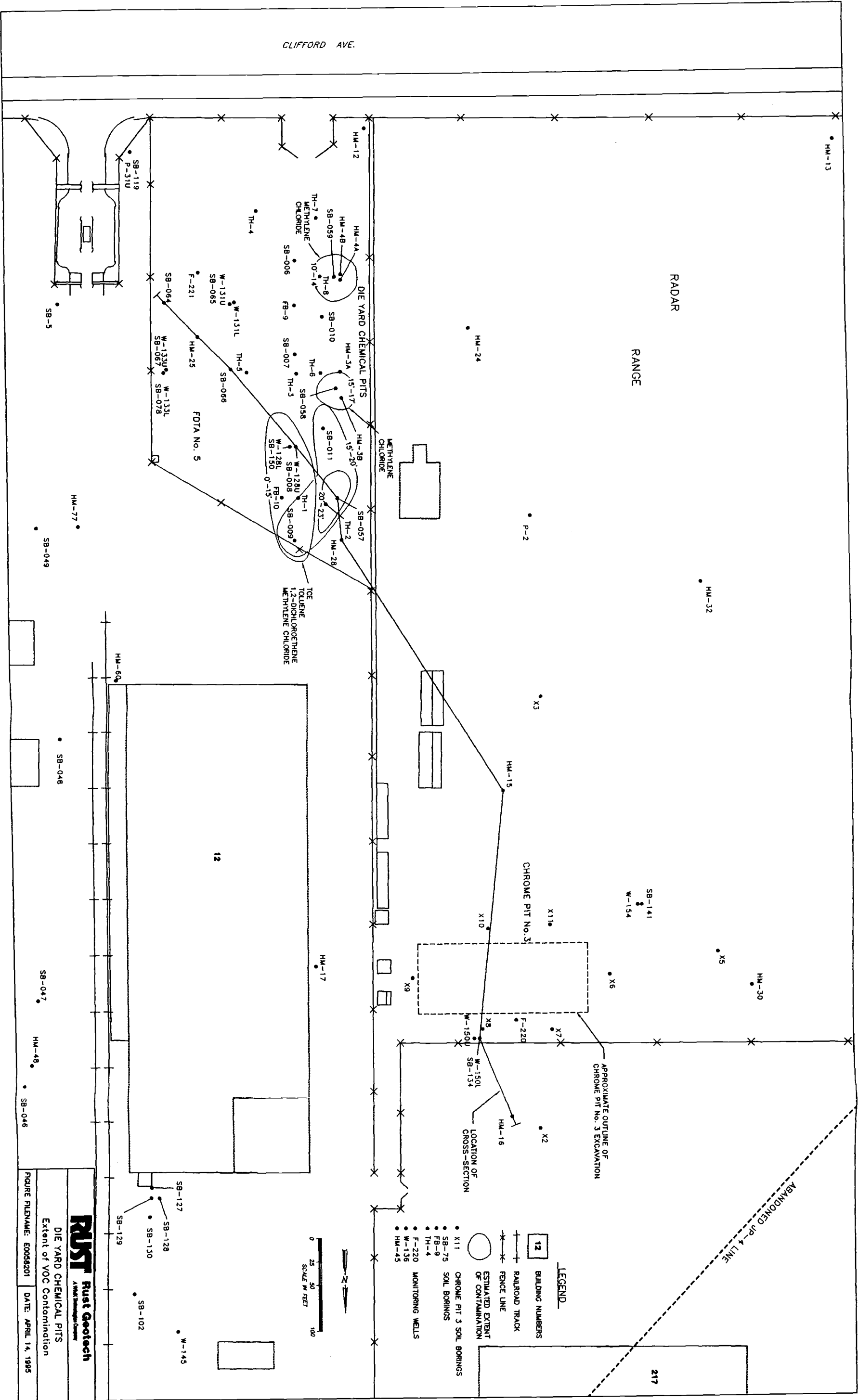


Figure 1-40. Extent of VOCs Detected at the DYCP.

methylene chloride (30,000 $\mu\text{g/kg}$), m,p-xylene (20,000 $\mu\text{g/kg}$), ethylbenzene (430 $\mu\text{g/kg}$), cyanide (0.38 mg/kg), zinc (0.48 mg/L), and chromium (0.13 mg/L). Wells HM-3A and HM-4A were destroyed by excavation of the die pits in 1983 and 1984.

In 1983, Hargis + Associates drilled monitoring wells HM-12, HM-24, HM-25, and HM-28 in the vicinity of the DYCP (see Figure 1-40). No analyses of soil samples are reported for these wells. Laboratory analyses of groundwater samples from HM-25 indicated the presence of benzene, chlorobenzene, ethylbenzene, trichloroethene, *trans*-1,2-dichloroethene, and dichlorobenzenes. The proximity of HM-25 to FDTA-5 suggests the primary source for this contamination is FDTA-5 with some contribution from the DYCP. Because the advective flow is to the northeast from HM-25, it is unlikely that leaks in solvent tanks at the south end of the Assembly Building/Parts Plant contributed to the contamination at HM-25. TCE was also detected in groundwater from HM-28. No significant concentrations of organic compounds were detected in groundwater from HM-12 and HM-24.

Intellus (1986) drilled two test borings, FB-9 and FB-10, adjacent to the eastern edge of the DYCP (see Figure 1-40). The lithologic logs for these two borings are in Appendix K of the RI. Organic vapor readings indicated VOCs (1 to 20 ppm) in FB-9 from 11 to 22 feet and from the ground surface to the Goodland Limestone at a depth of 17 feet in FB-10. Laboratory analyses detected a concentration of 297 $\mu\text{g/kg}$ of TCE at 8 to 8.5 feet in FB-10. No VOC contamination was indicated by analyses of soil samples from FB-9. Trace metals were found to be within levels typical of native soils (Intellus 1986). Organic vapor readings taken during drilling of monitoring well F-221 indicated that VOCs (1 to 15 ppm) were present in the drill cuttings from the surface to a depth of 11 feet. Between 11 and 19 feet, readings indicated levels of 15 to 25 ppm of VOCs in the soil. Laboratory analyses did not detect the presence of VOCs in the soils from F-221. It is not known whether the VOCs volatilized before the samples could be preserved. The proximity of F-221 to FDTA-5 suggests that a majority of any contaminants detected in the soils or groundwater were from FDTA-5. Because the advective flow from F-221 is to the northeast, it is unlikely that leaks in solvent tanks at the south end of the Assembly Building/Parts Plant contributed to the contamination at F-221.

Sampling and analysis of the soils in the entire DYCP pit area were needed to determine if contaminants exceeding background concentrations are present and if they are present, to determine their lateral and vertical extent. Results of previous investigations indicate that contaminants are still present following the interim remedial action of the pits.

Current Investigation: Ten soil borings (SB-006 through SB-011, SB-057 through SB-059, and SB-150) were drilled near the area of the excavated pits to determine the lateral and vertical extent of contamination (see Figure 1-40). No soil borings were drilled on the west side of the former pits because of extensive underground utilities in the area. The borings were drilled to the top of the water table and soil samples were collected from 5-foot intervals. Samples collected for VOCs were grab samples collected immediately upon opening the split-barrel sampler. The remaining samples were collected as composites from each 5-foot interval. The composite samples were analyzed for metals, cyanide, and semi-VOCs. The soil borings located within the excavated pits (SB-010, SB-011, SB-057, and SB-058) were sampled only from the 15- to 20-foot interval.

Summary of Soils

Geotech soil borings drilled in the DYCP area encountered competent bedrock at 6 feet to 16 feet below the surface (see Figure 1-41). The DYCP is situated on the west and northwest flanks of a bedrock high that is discussed in Section 1.5.3.7.

The generalized subsurface geology in the vicinity of this bedrock high is illustrated in Figure 1-42, which is a cross section that passes through the DYCP and the bedrock high. The location of the cross section is shown in Figure 1-40. The DYCP was paved over with asphalt and concrete that covers the upper sequence that includes silty clay, sandy clay, and occasional thin beds of limestone gravel. The thickness of this upper fine-grained unit ranges from a minimum of 4 feet in SB-007, near the top of the bedrock high, to more than 20 feet in SB-009, which is on the northwest flank of the bedrock structure. As a result of the previous excavation and grading of the site, there is an unknown amount of fill material and redistribution of the surficial Quaternary material. Up to 15 feet of fill was found in SB-010, SB-011, SB-057, SB-058, and SB-059. A basal sand and limestone gravel unit varies in thickness from 1 to 6 feet in the DYCP area and lies directly on bedrock of the Goodland Limestone.

Results of the Investigation

Two organic chemicals of concern (TCE and toluene) were detected in significant concentrations in the DYCP area (see Table 1-46 and the Appendix E of the RI). TCE was found in soil samples from SB-008 (0 to 15 feet), SB-009 (0 to 20 feet), SB-011 (15 to 16.5 feet), and SB-057 (15 to 23 feet), while toluene was present only in SB-011 at a 15- to 16.5-foot depth. 1,2-DCE was found in SB-008 and SB-009, with a maximum concentration detected at a depth of 15 to 16.5 feet in SB-011. Benzene, ethylbenzene, and xylene were detected in SB-011 from 15 to 16.5 feet. Low levels of methylene chloride were detected in all samples from SB-009, SB-010, and SB-011; somewhat elevated methylene chloride concentrations were found at SB-058 (1,600 $\mu\text{g/kg}$ from 15 to 17 foot depth), and the maximum concentration (40,000 $\mu\text{g/kg}$) was detected at a depth of 10 to 14 feet in SB-059. The areal extent of VOC contamination is shown Figure 1-40.

The maximum concentration of TCE detected is 200 $\mu\text{g/kg}$, which was found at a depth of 20 to 23 feet in SB-057. Figure 1-42 is a cross section that shows the cumulative sample interval for each borehole, the concentration of TCE present in soil and groundwater samples, and the estimated outline of contamination based on the current sampling and analyses. The TCE concentration appears to increase downward in SB-008 until the borehole encounters relatively impermeable limestone and shale bedrock. Borehole SB-057 is located to the northwest and is downgradient or downdip in respect to the bedrock high. SB-057 was sampled only below the expected clean fill and also indicates an increase in the concentration of TCE with depth. This observed trend of TCE concentration suggests that the DYCP is a source for TCE, which sinks because of its relative high density, and migrates downdip from the structurally high position in the DYCP toward SB-057. SB-057 and HM-28, from which concentrations of TCE are found in upper zone groundwater samples, are located on the northwest flank of the bedrock high, and adjacent to a poorly defined bedrock low.

Laboratory analyses did not reveal any significant contamination of semi-VOCs (see Table 1-47). 1,2-Dichlorobenzene was found in only one sample, while bis(2-ethylhexyl)phthalate was also found in laboratory blanks.

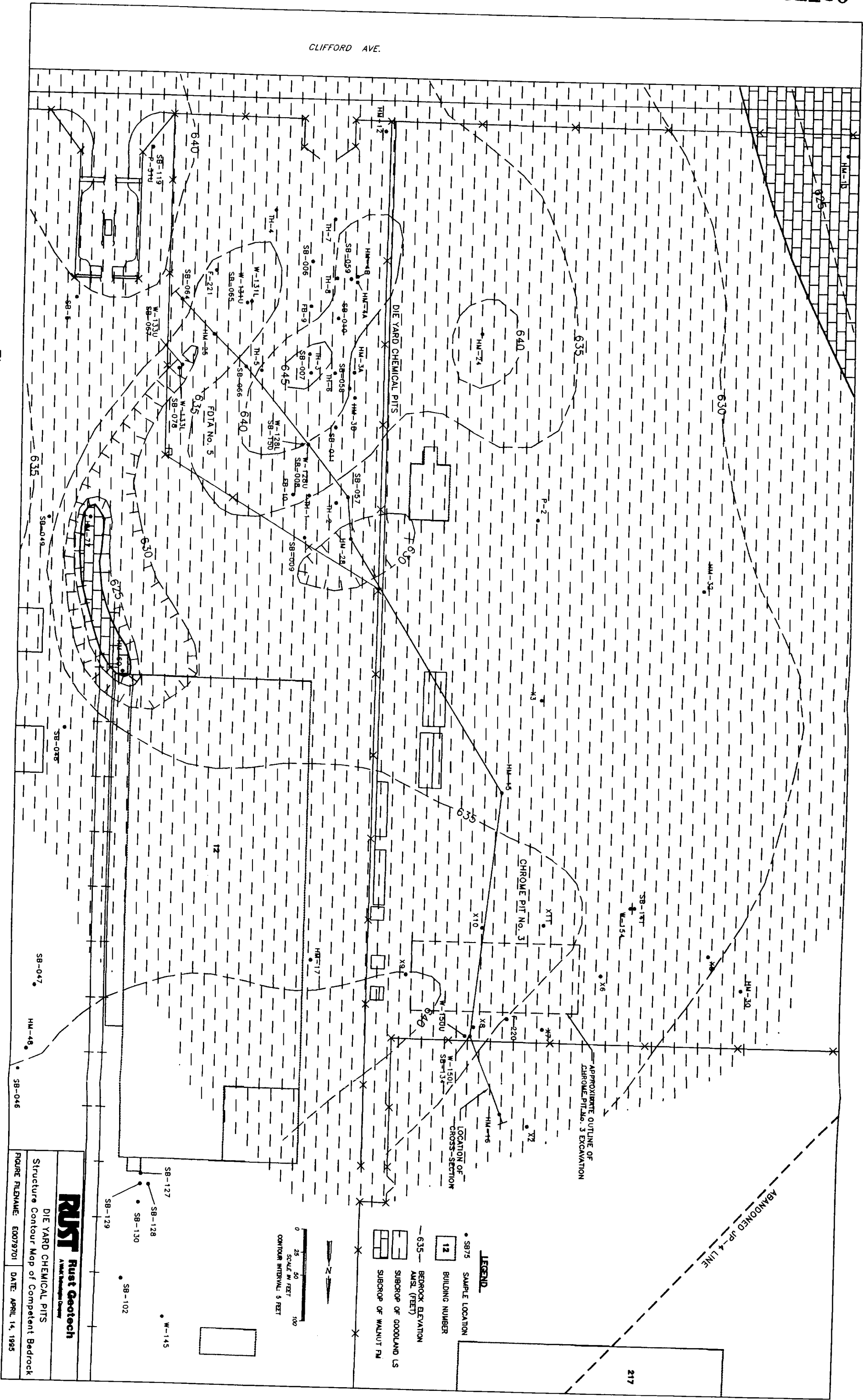


Figure 1-41. Structure Contour Map Showing Subcrop of Competent Bedrock at DYCP.

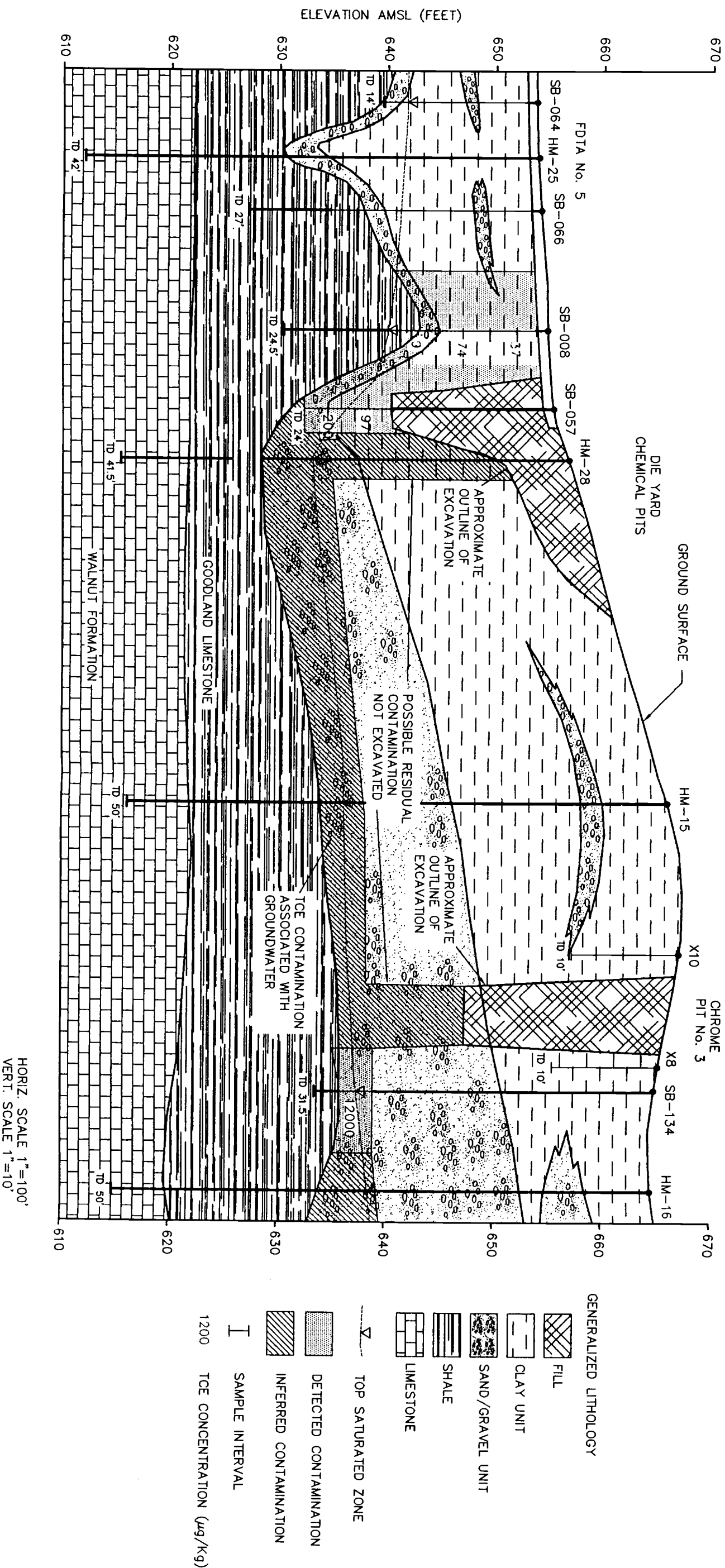


Figure 1-42. Cross Section of Generalized Subsurface Geology at DYCP.

Table 1-46 Summary of VOC Analytical Results for Soil Samples Obtained from the DYCP

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
1,1,2-Trichloroethane	(6)	18	25	3
1,2-Dichloroethene	(5)	310	25	3
Acetone	(11)	1,100	25	5
Benzene	(5)	8	25	1
Ethylbenzene	(5)	8	25	1
Methylene Chloride	(5)	40,000	25	9
Toluene	(5)	63	25	1
Trichloroethene	(6)	200	25	12
Xylene	(5)	28	25	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene and toluene were identified in the Baseline Risk Assessment as chemicals of concern.

Table 1-47. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from the DYCP

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Bis(2-ethylhexyl)phthalate	(760)	2,900	22	5
1,2-Dichlorobenzene	(740)	1,000	22	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

The concentrations of metals found in DYCP soil samples are within the upper range for background soils of the western United States (see Table 1-48).

TCLP Analytical Results

TCLP was used for analysis of VOCs, semi-VOCs, and inorganic constituents for sample SB-006-04, obtained 15 to 18 feet below ground level. Analysis of the liquid TCLP extract indicated all inorganic and organic analytes were below detection limit.

Table 1-48. Summary of Inorganic Sample Analyses for Soil Samples Obtained from the DYCP

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for the Western USA
Antimony	(9)	(12.3)	2.2	23	0
Arsenic	2.9	6.1	21.6	23	0
Beryllium	0.45B	0.88B	3.6	23	0
Cadmium	(0.9)	2	2.8	23	0
Chromium	5.8	95	196.6	23	0
Copper	3.1B	8.2	90.0	23	0
Lead	5.5	10.8	55.1	23	0
Nickel	5.1B	11.3	66.2	23	0
Selenium	(0.45)	(4.6)	1.4	23	0
Silver	(0.68)	(0.97)	1.4	23	0
Thallium	(0.45)	(0.49)	0.8	23	0
Zinc	12.3	24.4	176.2	23	0

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

Conclusions

The sampling and analyses have shown that significant contamination is still present in the DYCP area. A major concern is TCE, which has been found in soils from surface to bedrock depths and is present in groundwater throughout the area. Based on the analytical data, it appears that the DYCP site is a source for TCE contamination, which migrates down dip off the bedrock high. TCE contamination was identified adjacent to and below the excavated pits and in groundwater samples. The extent of contamination on the west side of the excavation has not been determined because underground utilities in the area impede sample collection. Additional sampling on the west side of the DYCP is necessary to determine if contamination is present. Because of the high density of underground utilities along the west side of the DYCP, sampling by mechanized methods could not be done safely. Sampling in this area would have to be conducted using hand methods, which generally would be restricted to use of shovels. Sampling, even by hand auger methods, could puncture plastic conduit, exposing utility wires and cables.

The DYCP is still an area with residual contamination and a potential source for future groundwater contamination. Excavation of contaminated soils identified by the borings would require removal of approximately 4,750 cubic yards of soil contaminated with TCE and an unknown amount of overlying clean fill. An additional volume of contaminated soil may exist to the west of the excavation, where

samples were not acquired because the presence of extensive underground utilities. Methylene chloride was identified in a 4-foot interval (10 to 14 feet) from SB-059 and in a 2-foot interval (15 to 17 feet) from SB-058. The estimated volume of detected contamination from the two areas is 360 cubic yards.

1.5.3.11 Fuel Saturation Area No. 1 (FSA-1) and Former USTs No. 19 and No. 20

Summary of Investigations

Previous Investigations: FSA-1 is located south and east of Facilities Building 14 (see Figure 1-43). Groundwater in this area reportedly became contaminated by fuels leaking from the underground distribution system during the mid-1970s to the early 1980s. The piping, consisting of 4-inch-diameter JP-4 lines, was abandoned in 1988. In addition, a fuel pumping station and two 12,000-gallon-capacity underground storage tanks, Nos. 19 and 20, were removed prior to December 22, 1988, which was the effective date of Federal Subtitle I regulations. These tanks were formerly located south of Facilities Building 14 and contained 2-butanone (Tank 19) and xylene (Tank 20).

Following removal of the underground storage tanks, analytical results of soil samples collected from the tank excavations indicate the presence of 2-butanone and xylene, compounds that are consistent with the former contents of the tanks. Ethylbenzene was also detected, which could indicate JP-4 contamination from the adjacent leaking underground piping. The soil samples were collected above the saturated zone at a depth of 8 feet below ground level. No further remedial action was performed after removal of the tanks. The excavations were backfilled and paved (Hargis + Associates 1989).

Prior to removal in 1984, Hargis + Associates installed monitoring wells HM-53, HM-55, P-6U, and P-6M, east of Building 14. Soil samples for chemical analyses were not collected from these borings. Intellus (1986) installed monitoring wells F-203, F-204, F-205, F-206, F-207, and F-211 around the perimeter of Building 14, but soil samples were not collected for chemical analyses. Radian Corporation (1987) drilled soil boring SB-4 east of Building 14 and collected two soil samples: one from the vadose zone at 9 to 10 feet below ground level and one from the saturated zone at 25 to 25.5 feet below ground level. Hydrocarbons were detected only in the saturated zone sample. Plate 3 shows boring locations and monitoring wells installed by previous investigations.

Current Investigation: Previous investigations concentrated on obtaining groundwater quality data; therefore, soil data were limited to a single soil boring (Radian, SB-4) and a few grab samples associated with the USTs excavation. The objective of the current investigation was to provide chemical analyses on soil samples that will more fully define the areal extent of potential contaminant source areas associated with leaks in the underground fuel lines and the former USTs. In addition, previous sampling at the former USTs was insufficient to determine if the saturated zone was impacted from the solvent products in the tanks.

Soil-gas measurements were performed along 300 feet of underground JP-4 fuel lines in an area suspected as the source of groundwater contamination. Soil samples for chemical analyses were obtained from follow-up borings located adjacent to the fuel line and in the immediate area of the former USTs. The following sections describe the results of these investigations.

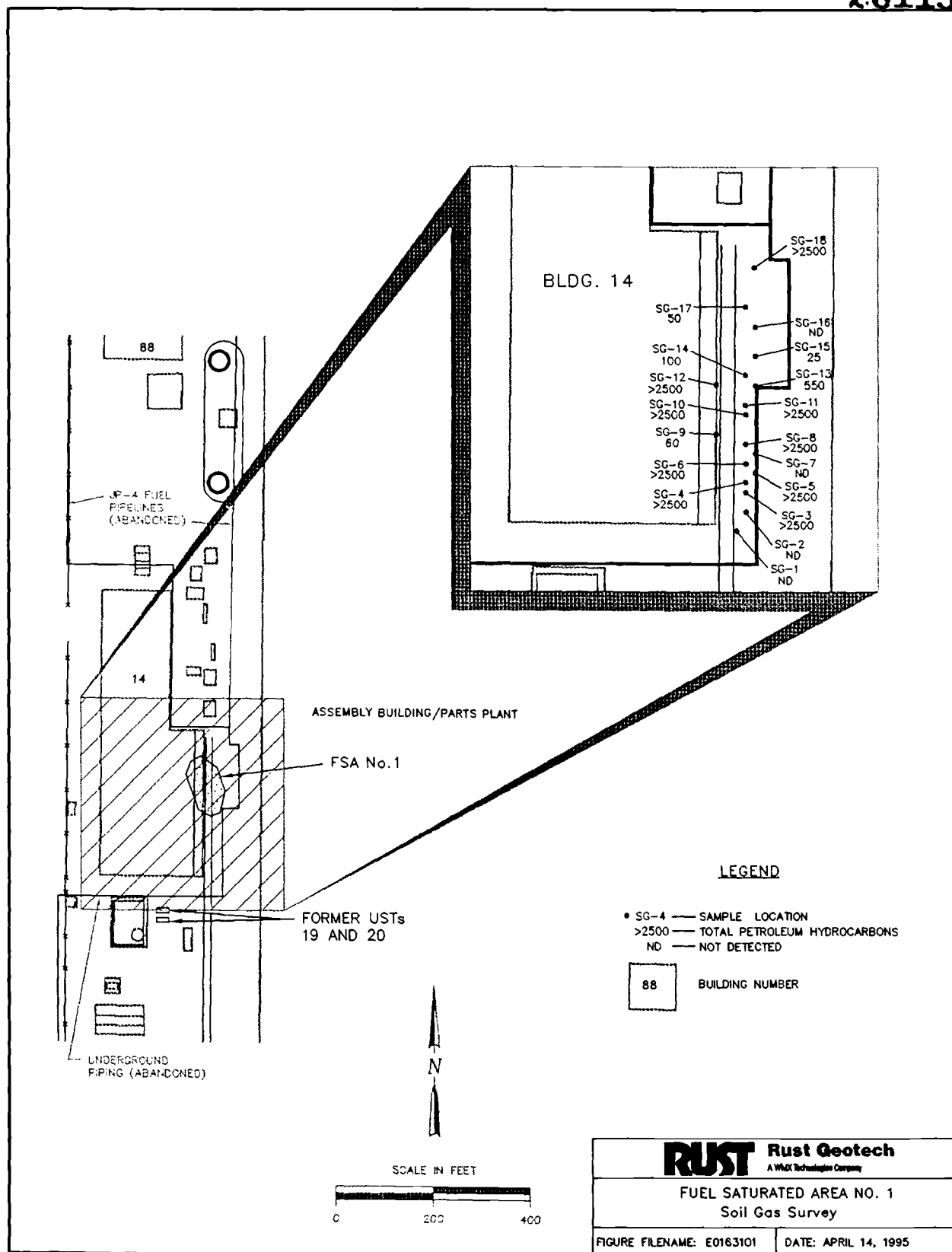


Figure 1-43. Results of the Soil Gas Survey at FSA-1.

Soil-Gas Survey

Soil-gas sampling was conducted along 300 feet of an active underground fuel line, just east of Building 14. Soil-gas was measured directly, at a nominal depth of 4 feet below ground level, with Draeger specific-indicator detectors that are sensitive to TPH. Measurement results are posted in Figure 1-43 and summarized in Table 1-49. Relatively high TPH values (greater than 2,500 ppm) were observed along most of the line. TPH was not detected in the two most southern locations, SG-1 and SG-2. Based on these results, several areas were selected for follow-up auger drilling to evaluate the extent of petroleum contaminated soils.

Table 1-49. TPH Measured in Soil-Gas at the FSA-1 and Former USTs No. 19 and 20

Sample Location	TPH (ppm)	Sample Location	TPH (ppm)
SG-1	ND	SG-10	>2,500
SG-2	ND	SG-11	>2,500
SG-3	>2,500	SG-12	>2,500
SG-4	>2,500	SG-13	550
SG-5	>2,500	SG-14	100
SG-6	>2,500	SG-15	25
SG-7	ND	SG-16	ND
SG-8	>2,500	SG-17	50
SG-9	60	SG-18	>2,500

Note: ND is not detected.

FSA-1 and Former UST Nos. 19 and 20 - Borehole Soil Sampling

Four boreholes, SB-120, -122, -123, and -124, were drilled around the perimeter of the former USTs excavation to determine the areal extent of contaminant migration. To test the soils for residual contamination in the vadose zone and to evaluate if the depth of contamination extends to the saturated zone, borehole SB-121 was located in the approximate center of the former tank excavation. Based on all current available data at the time the Work Plan was prepared, SB-133 was drilled to characterize the soils upgradient of the former USTs and downgradient conditions were tested from SB-131, -118, and -043. After completion of the RI field work the data indicate that this area of the site is characterized by a very flat water table with groundwater flow directions that are difficult to predict at a local scale. However, at a larger scale the data indicate flow is generally from south to north in the vicinity of Building 14. An east or west component of this flow cannot be predicted. Under conditions of flat hydraulic gradients temporal changes in recharge and hydraulic head can lead to flow directions which change as a function of time. Any particular point could therefore, have been upgradient or downgradient from the area of interest.

Eight boreholes, SB-039, -042, -132, -044, -109, -112, -116, and -079, were drilled in a north-to-south line adjacent to approximately 1,000 feet of underground piping. SB-111 and -125 were drilled west of the underground piping.

Soil samples were collected from the ground level to the top of the water table or until bedrock was encountered. Unconsolidated material was collected in 3-inch by 24-inch stainless-steel-split barrel samplers for the entire borehole. Borehole lithology and sampling intervals are summarized in Appendix A-2 of the RI. Samples from each 5-foot interval were composited and analyzed for semi-VOCs, TPH, and inorganics. From each 5-foot interval, one grab sample was collected for VOC analyses. A summary of the analytical data is presented in Appendix E of the RI.

VOC and TPH Soil Sample Results: Examination of the VOC and TPH soil sample analyses that are summarized in Table 1-50 reveal concentrations of 2-butanone, toluene, chloroform, and bromodichloromethane. The maximum values shown in Table 1-50 for these compounds were measured in soil samples obtained in the vicinity of the former USTs, at the south end of Building 14.

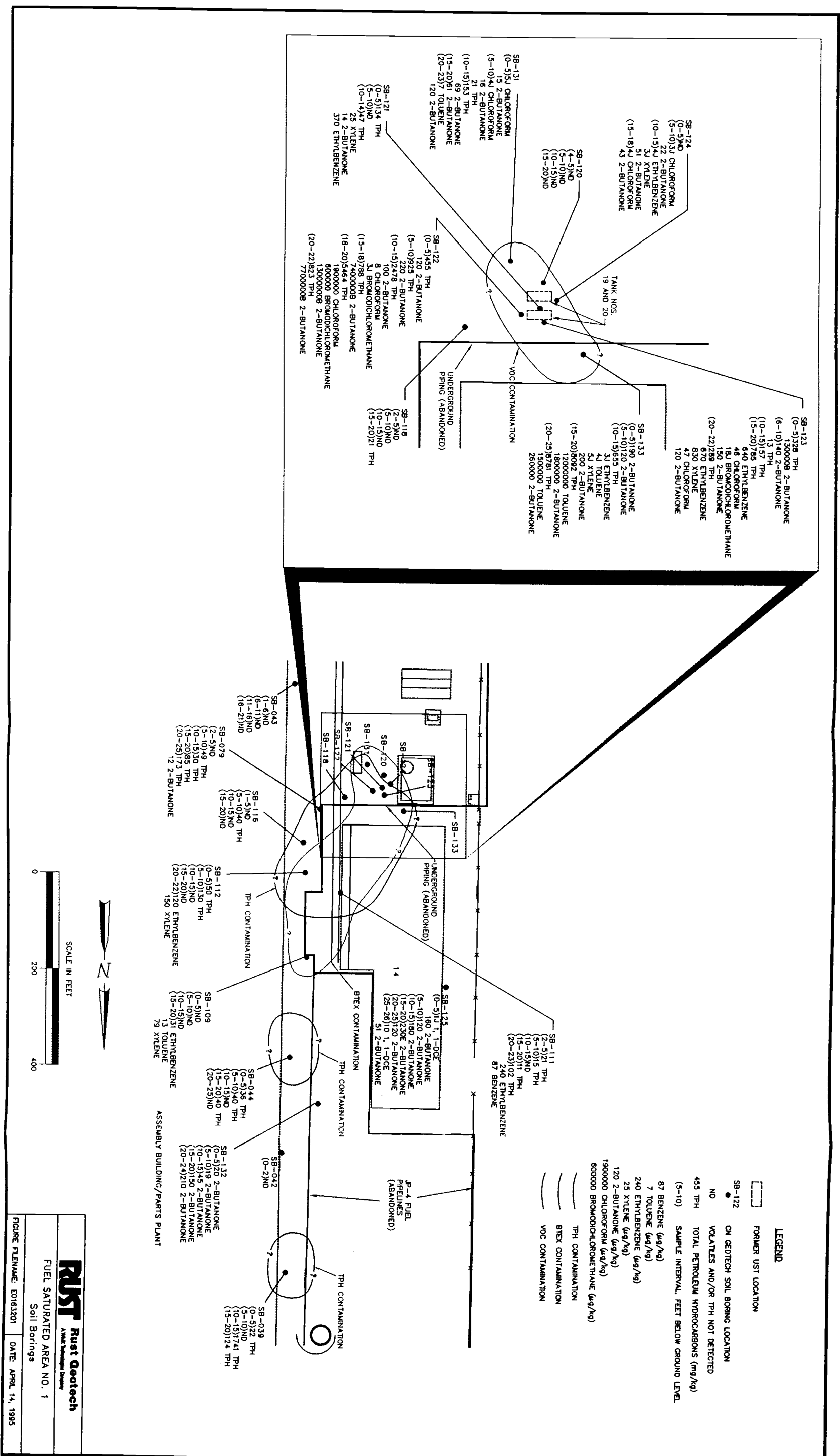
Table 1-50. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from the FSA-1 and Former USTs No. 19 and 20

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
1,1-Dichloroethene	(5)	10	104	1
2-Butanone	(10)	1,800,000	104	35
Acetone	(10)	61	104	18
Benzene	(5)	87	104	1
Bromodichloromethane	(5)	600,000	104	1
Chloroform	(5)	1,900,000	104	5
Ethylbenzene	(5)	670	104	6
Methylene Chloride	(5)	8	104	2
Toluene	(5)	12,000,000	104	5
Xylene	(5)	830	104	4
Total Petroleum Hydrocarbons	(10) mg/kg	8,781 mg/kg	102	44

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Toluene was identified by the Baseline Risk Assessment as a chemical of concern.

Figure 1-44 shows the results of the VOC analyses posted at each borehole location. The highest 2-butanone values occur at SB-122 and -133. SB-133 also contains the highest concentration of toluene (12,000,000 µg/kg). The one instance where bromodichloromethane exceeds the CRQL (600,000 µg/kg) and the highest chloroform value (1,900,000 µg/kg) occurs in this area, at SB-122.

In addition to the maximum value (1,800,000 µg/kg) reported for 2-butanone at SB-133, this compound also occurs in a high frequency of samples (SB-079, -120, -121, -123, -124, and -131), although at much lower levels. 2-Butanone in these samples reflects contamination from the former UST No. 19, as shown by the pink line in Figure 1-44. Xylene found in these samples is probably associated with contamination from the former UST No. 20. Chloroform is commonly added to potable water supplies as treatment and may explain the occurrence of this compound. The source of the bromodichloromethane and toluene found in SB-122 and SB-133, is somewhat troublesome because historical records do not indicate storage



of these compounds in USTs No. 19 or 20, and is probably indicative of an unknown source unrelated to the former USTs or the underground piping. Benzene (87 $\mu\text{g/kg}$) and the occurrences of ethylbenzene and TPH are most likely related to the JP-4 underground piping.

These data indicate that the vadose zone in the vicinity of the former tank excavation is contaminated with 2-butanone, chloroform, toluene, and bromodichloromethane, as shown by the area delineated in Figure 1-44. The extent of contamination is approximately 100-feet wide by 200-feet long and extends to the saturated zone which varies between 20- to 25-feet below ground level. The extent of relatively high VOC contamination is associated with SB-122 and -133 and limited to a zone between 15- and 25-feet below the ground surface. Soil sampling from this zone indicates 2-butanone fails the TCLP as discussed in Section 1.5.3.11.

Volatiles were also detected at two isolated locations (SB-125 and -132) at the north end of Building 14. 2-Butanone concentrations, ranging from 19 to 230E $\mu\text{g/kg}$, were detected in every sample obtained from SB-125 and -132. At location SB-125, 1,1-dichloroethene was detected at concentrations of 1J and 10 $\mu\text{g/kg}$. These are two isolated locations that do not appear to be related to each other or to the source of the contamination found in adjacent borings. The concentrations are relatively low which suggest possible contamination or cross-contamination of field equipment after sampling the USTs No. 19 and 20 where extremely high levels of 2-butanone were detected in saturated zone samples. However, because the entire soil column for both boreholes indicates 2-butanone contamination, a groundwater pathway is not probable. On the other hand, a surface spill cannot be ruled out. During field activities at least one spill of 2-butanone was noted by the Geotech field crew.

Acetone was detected in 18 samples above the CRQL and methylene chloride detected in two samples, but these compounds are common laboratory contaminants (EPA 1988), and their random occurrence at relatively low concentrations is probably not indicative of environmental contamination. The maximum value for acetone is 61 $\mu\text{g/kg}$ and 8 $\mu\text{g/kg}$ for methylene chloride. For these reasons, results for these compounds are not posted in Figure 1-44.

BTEX contamination is associated with a portion of the underground fuel piping in the vicinity of the USTs No. 19 and 20 excavation and extends northeast to SB-109 (Figure 1-44). BTEX contamination in these borings occurs mostly in samples from the saturated zone and in relatively low concentrations, except for toluene in SB-133, which is probably related to a source other than the underground piping.

Relatively high TPH concentrations associated with leaks in the underground piping occur in SB-122 (up to 5,464 mg/kg), SB-123 (up to 785 mg/kg), and SB-133 (up to 8,781 mg/kg). TPH also appears more widespread than BTEX, occurring in both vadose- and saturated-zone samples. The TPH contamination occurring at two borings north of the BTEX plume (SB-044 and -039) reflects multiple leaks in different parts of the underground piping. TPH values from SB-044 are relatively low, ranging from 36 mg/kg for the 0- to 5-foot sample to 40 mg/kg for the 5- to 10-foot and 15- to 20-foot samples. Higher values, up to 1,741 mg/kg for the 10- to 15-foot sample, are observed at SB-039.

Semi-VOC Soil Sample Results: Results of the semi-VOC analyses are summarized in Table 1-51. The most numerous semi-VOC reported above the CRQL is bis(2-ethylhexyl)phthalate. However, because phthalates are common laboratory contaminants (EPA 1988), this compound is most likely not associated with environmental contamination. This assumption is further supported by the fact that

Table 1-51. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from the FSA No. 1 and USTs No. 19 and 20

Analyte	Minimum μg/kg	Maximum μg/kg	No. of Samples Analyzed	No. Above CRQL
2-Methylnaphthalene	(680)	50,000	103	9
Benzo(a)anthracene	(680)	1,300	103	3
Benzo(b)fluoranthene	(680)	11,000	103	3
Benzo(g,h,i)perylene	(680)	6,400	103	1
Benzo(k)fluoranthene	(680)	6,400	103	1
Bis(2-ethylhexyl) phthalate	(720)	6,500	103	40
Chrysene	(680)	1,700	103	3
Fluoranthene	(680)	3,900	103	4
Indeno(1,2,3-cd)pyrene	(680)	6,200	103	1
Naphthalene	(680)	1,100	103	2
Phenanthrene	(680)	3,500	103	3
Pyrene	(680)	8,100	103	4

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, naphthalene, and 2-methylnaphthalene were identified by the Baseline Risk Assessment as chemicals of concern.

bis(2-ethylhexyl)phthalate occurs randomly, and results of duplicate analyses are inconsistent. For example, analytical results for the sample obtained at the 15- to 20-foot depth interval from SB-039 was reported at 210J μg/kg. The duplicate analysis of this sample was reported at 2,200 μg/kg, an order of magnitude higher.

The remaining semi-VOCs reported above the CRQL are typically related to coal tar, crude oil, and petroleum products. These compounds occur only in the boreholes that are associated with the most southern TPH contamination delineated in Figure 1-44 and probably reflect contamination from the leaking underground piping. In some cases, these semi-VOCs may also be indicative of small pieces of asphalt incorporated in the sample. Evidence of asphalt was noted by the field geologist for SB-121 at 14.7-feet below ground level (see Appendix A-2 of the RI). Asphalt at this location is probably part of the pad for the underground storage tanks, since concrete was encountered immediately below the asphalt.

Dibenzofuran and pentachlorophenol are the only semi-VOCs detected that are not associated with coal tar, crude oil, and petroleum product. Dibenzofuran was detected in one sample in both SB-131 and -122. Pentachlorophenol was detected in one sample in SB-039. In both cases they were not detected above the CRQL but were reported as estimated quantities (qualified "J"). The limited occurrence of these compounds, combined with the fact that field duplicates and laboratory re-analyses do not confirm their presence, suggest they are not associated with environmental contamination. For example, dibenzofuran was detected at 300J and 130J μg/kg in SB-131 and -122, respectively, but the compound was not detected by the laboratory re-analyses of the samples. Similarly, pentachlorophenol was detected at 860J μg/kg in SB-039 but was not detected in the field duplicate.

Inorganic Soil Sample Results: Results of soil sample analyses for the 12 priority pollutant metals are summarized in Table 1-52. Silver and selenium were not detected in any sample. Except for antimony, all the values reported for the remaining analytes are within the range expected for natural background concentrations. Five samples exceeded the upper limit of natural background for antimony (twice at SB-044, and once at SB-111, -116, and -121). For these cases, all values were above the IDL but less than the CRDL. The values also appear isolated and random, suggesting they are elevated because of natural processes.

Table 1-52. Summary of Inorganic Analytical Results for Soil Samples Obtained from the FSA No. 1 and Former USTs No. 19 and 20

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for Western USA
Antimony	(8.4)	11.1B	2.2	74	5
Arsenic	(0.64)	5.5	21.6	74	0
Beryllium	(0.21)	1.2	3.6	74	0
Cadmium	(0.84)	1.8	2.8	74	0
Chromium	1.5B	29.2B	196.6	74	0
Copper	1.3B	21.4	90.0	74	0
Lead	0.87	37	55.1	74	0
Nickel	(3.5)	16.1	66.2	74	0
Selenium	(0.42)	(4.6)	1.4	74	0
Silver	(0.65)	(0.98)	1.4	74	0
Thallium	(0.42)	0.54B	0.8	74	0
Zinc	4.5	65.3	176.2	74	0

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified by the Baseline Risk Assessment as chemicals of concern.

TCLP Analytical Results: VOC analyses on soils collected from SB-122 reveal extremely high concentrations of 2-butanone that resulted from product leaking from the former USTs (Section 1.5.3.11). In addition, the highest concentration of bromodichloromethane and chloroform are observed at this location. Therefore, TCLP analyses was performed on a soil sample collected from SB-122 at a depth of 15- to 20-feet below ground level. The TCLP, designed to determine the mobility of contaminants present in waste material, was submitted for VOC and semi-VOC determinations. Materials that fail the TCLP test are classified as hazardous waste.

Results of the TCLP analyses indicate the presence of 2-butanone at a concentration of 440,000 $\mu\text{g/L}$ in the liquid extract. The TCLP regulatory level for this compound is 200,000 $\mu\text{g/L}$ (40 CFR Part 261.24, Table 1), therefore, the soil is considered a toxicity characteristic waste. No other VOCs or any semi-VOCs were detected in this sample.

Vadose and saturated zone soil samples collected in the vicinity of the former USTs No. 19 and 20 indicate the presence of 2-butanone, toluene, chloroform, ethylbenzene, xylene, and bromodichloromethane (see Figure 1-44). Concentrations of 2-butanone, toluene, chloroform, and bromodichloromethane up to 1,800,000, 12,000,000, 1,900,000, and 600,000 $\mu\text{g}/\text{kg}$, respectively, were detected in SB-122 and -133 from a zone between 15- and 25-feet below ground surface. A sample obtained from this zone failed the TCLP test for 2-butanone.

Petroleum-related hydrocarbons found in soil samples reflect leaks in different parts of the underground fuel pipeline. Relatively low concentrations of BTEX occur mostly in samples obtained from the saturated zone. TPH appear more widespread than BTEX, occurring in both vadose and saturated zone samples. TPH concentrations occur up to 5,464 $\mu\text{g}/\text{kg}$ (SB-122), 785 $\mu\text{g}/\text{kg}$ (SB-123), 8,781 $\mu\text{g}/\text{kg}$ (SB-133), and 1,741 $\mu\text{g}/\text{kg}$ (SB-039).

Several semi-VOCs that are typically related to petroleum products were detected above the CRQL. These compounds are present only in soil samples associated with the most southern TPH contamination delineated in Figure 1-44, which indicates the source is related to fuel leaks in the underground piping.

Five samples exceeded the upper limit of natural background for antimony (twice at SB-044, and once at SB-111, -116, and -121). For these cases, all values were above the IDL but less than the CRDL. The values also appear isolated and random, suggesting they are elevated because of natural processes. No other priority pollutant metal was detected at a concentration greater than the upper limit of natural background.

1.5.3.12 Fuel Saturation Area No. 2

Summary of Investigations

Previous Investigations: Fuel Saturation Area No. 2 (FSA-2), located northwest of Facilities Building No. 176, is a site which reportedly was saturated by fuels leaking from a buried fuel pipeline in the 1970s and early 1980s (CH2M Hill).

Well HM-80 was drilled by Hargis + Associates (1985) at the suspected location of FSA-2 (Figure 1-45). No soil contamination was reported.

Intellus (1986) drilled one test boring (FB-4) and one monitoring well (F-212). Analyses of soil samples did not reveal the presence of fuel constituents. These negative findings together with results from analyses of previously drilled HM-80 suggest that FSA-2 had not been properly located.

IRP Phase II Stage I activities by Radian in 1986 consisted of drilling three boreholes (SB-1, SB-2, and SB-3) along the length of the buried fuel line. Soil samples were collected and analyzed for halogenated volatiles and aromatics, and hydrocarbon fuels. Organic compounds were detected at low levels with the exception of the SB-2 interval from 5 to 6 feet, where hydrocarbon fuels (4,600 mg/kg) and 1,1-DCE (12 $\mu\text{g}/\text{kg}$) were detected in the soils. The concentration of contaminants decreased below the 5- to 6-foot interval. Analytical results may be found in Table 1-43 (Radian 1987). No remediation or removal of soils was reported.

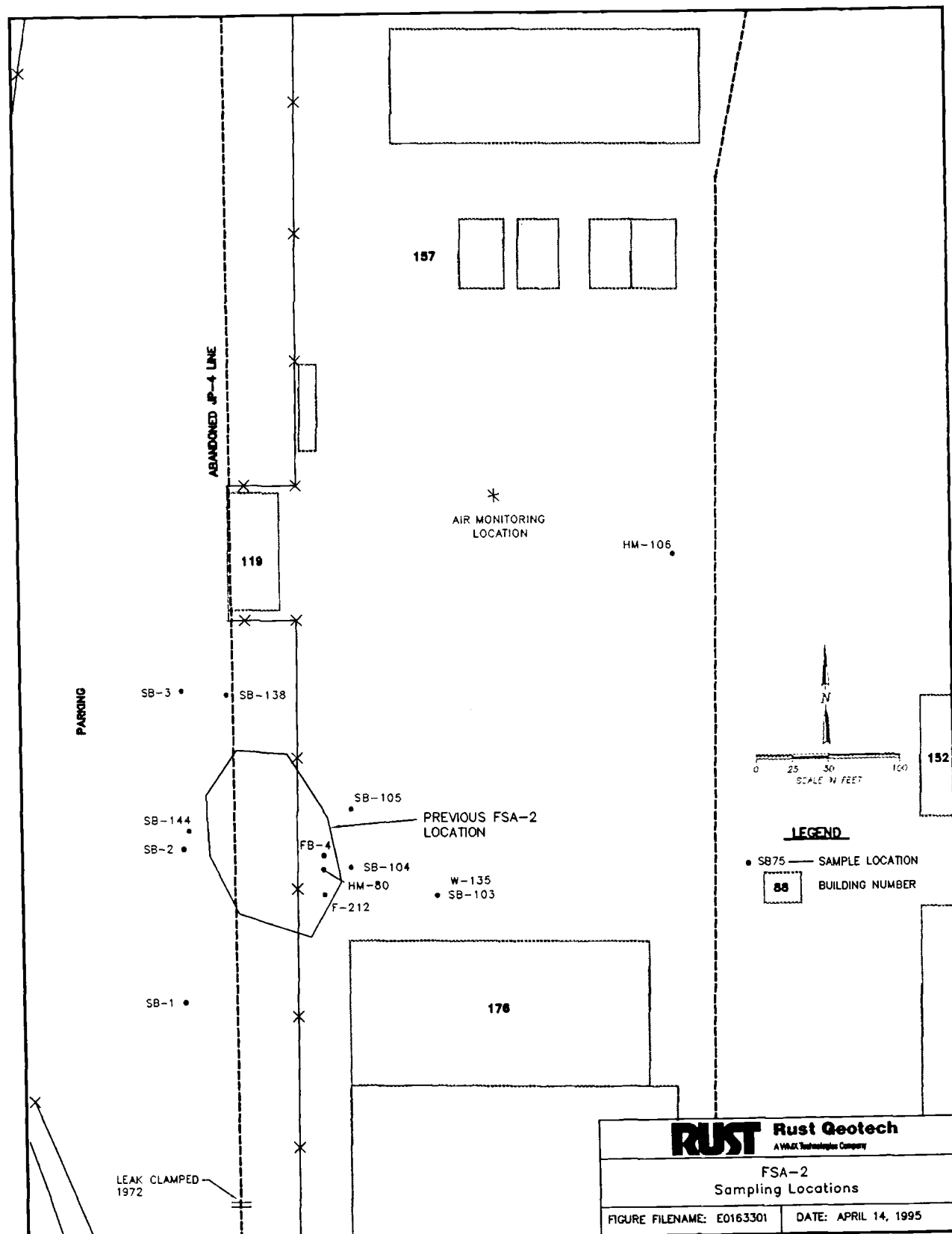


Figure 1-45. Borehole Soil Sample Locations at FSA-2.

Current Investigation: Soil-gas sampling was performed east of the area delineated in 1985 by Hargis + Associates. Samples were collected at 14 locations from a nominal depth of four feet below ground level and analyzed directly in the field with Draeger specific-indicator detectors that are sensitive to TPH. Figure 1-46 shows the locations where the Draeger measurements were performed. TPH was not detected in any sample, therefore, additional samples were collected on sorbent tubes, at five selected locations, and returned to the laboratory for more definitive analyses by GC/MS.

Concentrations of petroleum related hydrocarbons, including the aromatic compounds BTEX and relatively heavier molecular weight compounds such as cyclohexane, 4-methylheptane, and methylcyclohexane, were detected in all five samples analyzed by GC/MS. Concentrations of PCE, TCE, and 1,1,1-TCA were also detected in 3 of the 5 samples analyzed by GC/MS, however, these chlorinated hydrocarbons are not typically associated with petroleum products. Results of the GC/MS analyses are summarized in Table 1-53 and plotted in Figure 1-46. TPH values presented in the table and figure represent the sum of all petroleum related hydrocarbons measured by GC/MS and may include estimated and tentatively identified compounds.

Table 1-53. Results of Soil-Gas Measurements Performed at Fuel Saturation Area No. 2

SAMPLE LOCATION	TPH (µg/L)	PCE (ng/L)	TCE (ng/L)	1,1,1-TCA (ng/L)
E7	0.5	8	(5)	11
B5	0.3	18	(5)	14
B5-DUP	0.3	(5)	(5)	(5)
B3	0.6	(5)	(5)	(5)
A4	0.5	(5)	(5)	(5)
A7	0.5	(5)	9	(5)

Notes: 1) Concentration in parentheses indicates the compound was not detected at reported value.

2) B5-DUP is a field duplicate at location B5. The value plotted in Figure 4.3.12-2 represents the mean for the duplicate samples. For below detection data, one-half the detection limit has been used to calculate the mean.

Results of the soil-gas survey were used to guide the placement of soil borings. An EPA representative reviewed previous data collected at FSA-2, evaluated results of the soil-gas investigation, and in agreement with Geotech, selected five soil boring locations in the FSA-2 area (Figure 145). SB-103, SB-104, and SB-105 were drilled at grid points where soil-gas measurements indicated anomalous amounts of contamination. Boring SB-103 was converted into monitoring well W-135. SB-138 and SB-144 were drilled to the north and west, respectively, of the FSA-2 area in a parking lot outside the security fence. Soil borings were drilled from the surface to the top of the bedrock and samples collected in 3-foot intervals. Samples for VOCs were grab samples from each 3-foot interval. The remaining samples were composites of each interval and were analyzed for semi-VOCs and TPH.

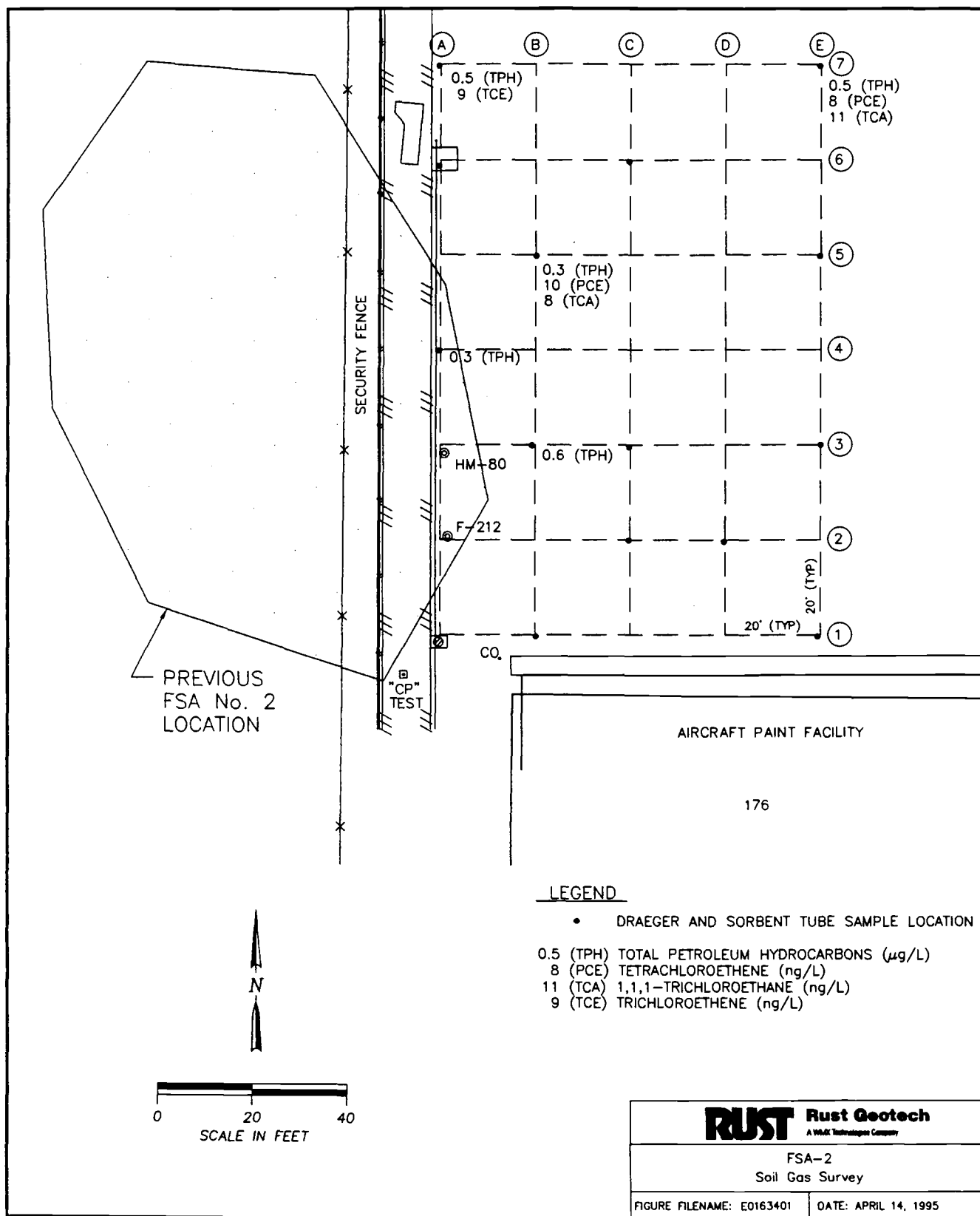


Figure 1-46. Soil Gas Sample Locations at FSA-2.

Summary of Soils

The locations of the five soil borings are covered with 4 inches to 2 feet of concrete or asphalt. Below pavement there are 2 feet to 6 feet of unconsolidated sediments and fill. The poorly sorted material may be described as mostly clay mixed with some gravel, sand, and silt. This unconsolidated material overlies weathered shale and limestone of the Goodland Limestone which varies in thickness from 1.5 feet to 7 feet in SB-103, SB-104, and SB-105. Hard limestone of the Walnut Formation was reached at 11.5 feet below the surface in SB-103. Boreholes SB-138 and SB-144 are located downslope to the northwest and are in a topographically lower position relative to SB-103, SB-104, and SB-105. The alluvium and fill in SB-138 and SB-144 lie directly on hard, gray Walnut Formation which was encountered at 4.5 feet to 5.5 feet depth. Lithologies encountered in the FSA-2 area are contained in the Borehole Lithology Logs (see Appendix A-2 of the RI).

Results of the Investigation

Laboratory analyses of the soil samples from FSA-2 failed to detect significant contamination of the chemicals of concern. Semi-VOC bis(2-ethylhexyl)phthalate was detected in soil samples from the surface to a depth of 11 feet in SB-103, at concentrations up to 2,600 $\mu\text{g/kg}$ (Table 1-54). However, this compound was measured at a higher concentration in the laboratory blank (Appendix E of the RI).

Table 1-54. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from FSA-2

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
Bis(2-ethylhexyl)phthalate	(760)	2,600	12	3

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Low levels (17 to 38 mg/kg) of TPH were measured in the upper 10 feet of soil from all five borings (see Table 1-55). Low levels of acetone and 2-butanone, which are common laboratory contaminants, were detected in the samples.

Table 1-55. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from FSA-2

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
Acetone	(11)	68	12	8
2-Butanone	(11)	20	12	2
Total Petroleum Hydrocarbons	(10) mg/kg	38 mg/kg	12	6

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Conclusions

The sampling and analysis of soil from five boreholes in the FSA-2 area did not find significant contamination. The compound bis(2-ethylhexyl)phthalate is a common laboratory contaminant and was also found in laboratory blanks for these samples. The concentration of TPH detected in soil samples is relatively low, although apparently widespread.

The fuel related contamination reported in Radian borehole SB-2 may be attributed to a previous leak in the now abandoned JP-4 line. A GD map shows the location of a reported leak to the south of FSA-2 that was clamped in 1972 (see Figure 1-45). SB-2 appears to be in a topographically lower position than the JP-4 line. Drainage of leaking fuel might collect downslope in the vicinity of SB-2. An alternative source for contamination could be a surface spill in the area that migrated to the SB-2 location.

The detection of a significant concentration of hydrocarbon fuels in SB-2 and the reported location of a leak in the JP-4 line to the south of FSA-2 indicates the need for additional sampling in this area.

1.5.3.13 Fuel Saturation Area No. 3 and UST-30

Summary of Investigations

Previous Investigations: Fuel Saturated Area No. 3 (FSA-3) located immediately east of Meandering Road between Facilities Building Nos. 135 and 142 (Figure 1-47), is a site contaminated by fuels from buried fuel pipelines that leaked during the 1970s and early 1980s. The FSA-3 area also has numerous underground utilities and several UST sites.

Fuel-related floating product has been observed in seven of 13 wells in the area of FSA-3. Analytical results of groundwater samples show that the groundwater at FSA-3 contains anomalous concentrations of VOCs, semi-VOCs, and fuel hydrocarbons. Contaminants found in groundwater at FSA-3 in concentrations that exceed Federal standards include benzene, ethylbenzene, toluene, chlorobenzene, TCE, and naphthalene.

Hargis + Associates drilled monitoring well HM-78 north of Building No. 134 to monitor groundwater conditions in the reported vicinity of FSA-3 (see Figure 1-48). Fuel saturation was discovered with about 2 feet of product floating on top of the upper zone groundwater. Contaminants identified include benzene, ethylbenzene, toluene, chlorobenzene, and TCE. Soil sampling and analysis was not reported.

Intellus completed a geophysical conductivity survey over the FSA-3 area to help delineate the extent of contamination. Cone penetrometer soundings were taken to aid in the identification of vertical and horizontal changes in lithology, to determine the Upper Zone/Walnut Formation contact, and to aid in location and design of monitoring wells. Six wells (F-200, F-201, F-202, F-208, F-209, and F-210) were drilled to monitor groundwater contamination (see Figure 1-47). A layer of JP-4 was present at F-201, F-202, and HM-78, with low concentrations of JP-4 found in F-200 and F-210. TCE was detected in F-200, F-202, F-210, and HM-78. Chlorinated solvent contamination is reported in well F-208. Soil sampling and analysis was not reported.

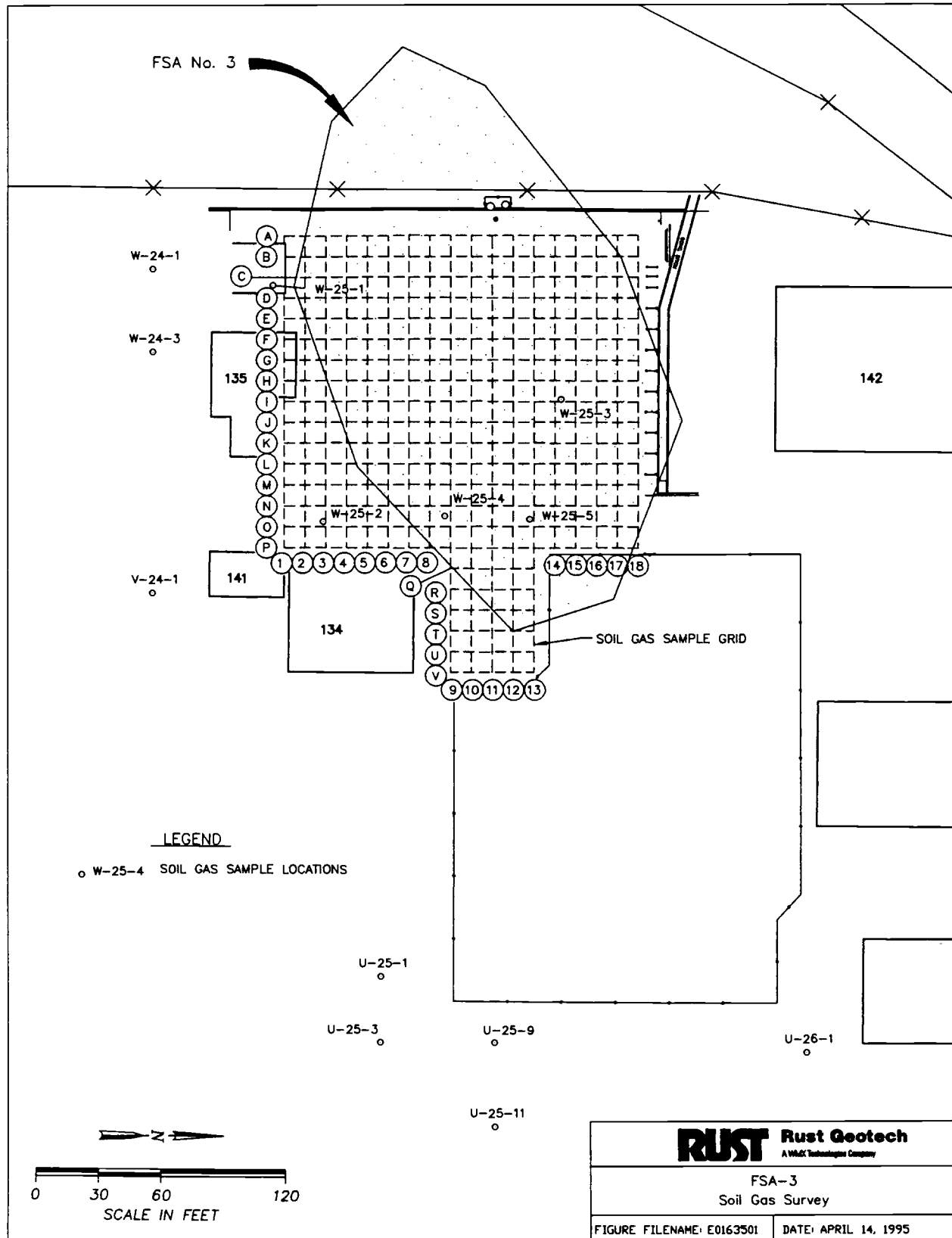


Figure 1-47. Soil Gas Sample Locations at FSA-3.

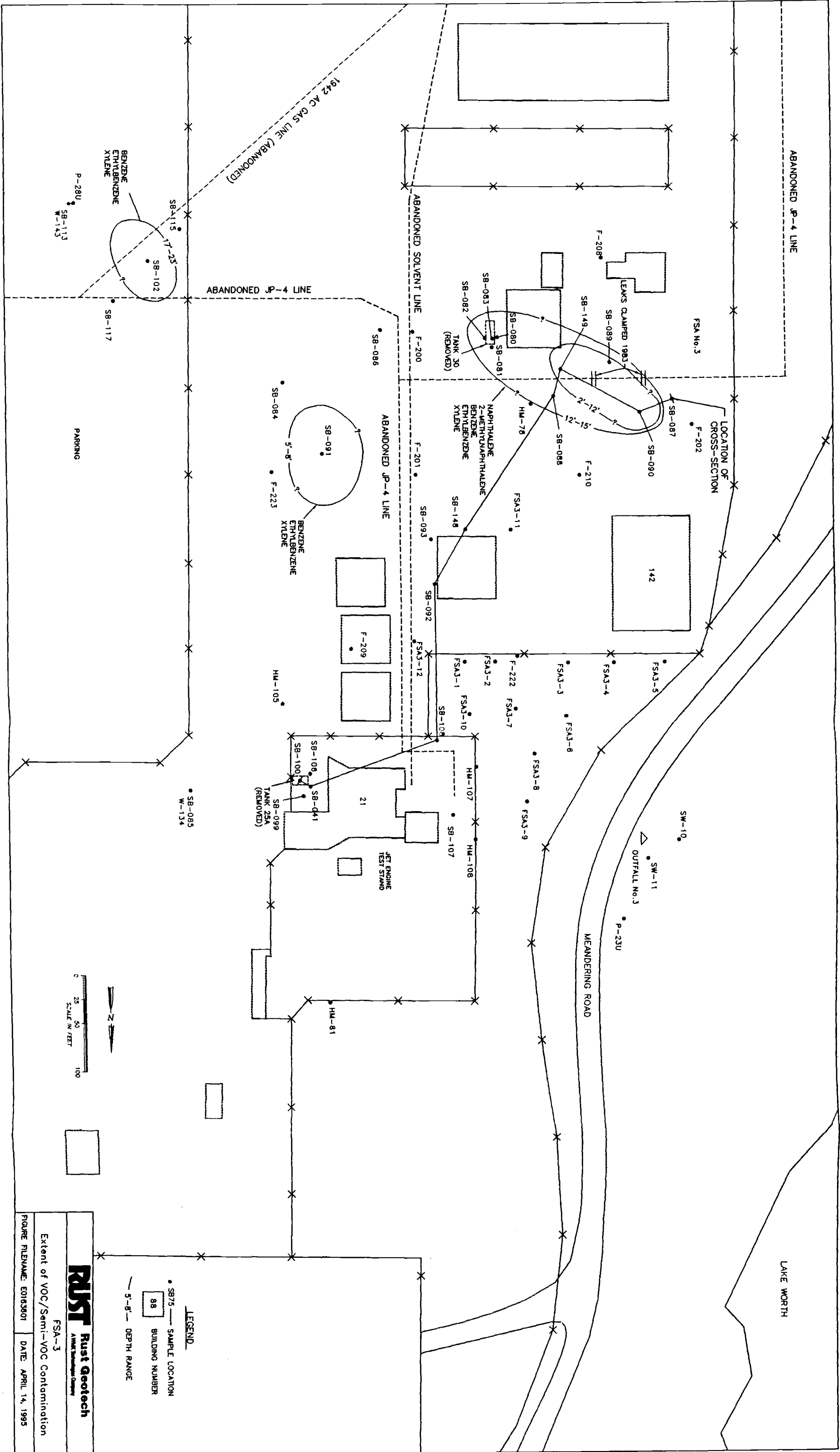


Figure 1-48. Extent of VOCs and Semi-VOCs in the Vadose Zone Detected at FSA-3.

In June 1988, Hargis + Associates drilled two soil borings (FSA3-5 and FSA3-9) and ten Upper Zone monitoring wells (FSA3-1, -2, -3, -4, -6, -7, -8, -10, -11, and -12) in the area downgradient of FSA-3 (see Figure 1-48). The purpose for drilling these boreholes was to further define the lateral and vertical extent of free product, to delineate subsurface lithology and groundwater flow directions, and to determine a suitable location for a pipeline cut-off wall system to prevent the spread of contamination. The relative concentrations of fuel vapor in boreholes and drill cuttings were monitored using a PID. Fuel vapor and floating product were detected in the subsurface throughout the Fuel Test Area (FTA).

UST-30, located to the southeast of FSA-3, was removed prior to December 22, 1988. A soil sample (6-501B) taken from the bottom of the excavation was found to be contaminated with BETX. No soil was removed.

Current Investigation: Twenty monitoring wells from previous investigations provide information throughout FSA-3. However, additional soil sample data were required around the perimeter of FSA-3 to better define the lateral and vertical extent of contamination. Prior investigations on the north side of FSA-3 provided sufficient data to define the extent of contamination in that direction. Shallow bedrock to the west and northwest limits the investigation on those sides but allows definition to the edge of contamination. The current investigation concentrated on the south and east sides of FSA-3. A limited soil-gas investigation was conducted on the west side of FSA-3.

The soil-gas survey was conducted as a screening tool across the FSA-3 area to help define the lateral extent of soils contamination. A sampling grid was set over the extent of contamination as mapped by prior investigations. Samples were collected from a nominal depth of 4-feet below ground level and analyzed directly in the field with Draeger specific indicator detectors that are sensitive to TPH. When contamination was found to extend past the grid, selected points were investigated to better define the extent of contamination. Numerous underground utilities and storage of structural steel in the area investigated restricted the locations available for sampling. The sampling locations are shown in Figure 1-47. Results of the TPH measurements are shown in Table 1-56.

On the basis of previous data and the approximate extent of contamination outlined by the soil-gas survey, 13 soil borings (SB-84, SB-86 to SB-93, SB-107, SB-108, SB-148, and SB-149) were drilled two at locations in the FSA-3 area to help define the lateral and vertical extent of contamination. Soil samples were collected at 3-foot intervals from the surface to the top of the water table. The samples for VOCs were grab samples from each 3-foot interval. The remaining samples were composites of each interval. Composite samples were analyzed for semi-VOCs and TPH. One sample from SB-149 was analyzed for TCLP characteristics to determine the effects of leaching for various remedial action technologies.

Four borings (SB-080 to SB-083) were placed around the perimeter of the site of former UST-30, which is located to the southeast of the FSA-3 area. Soil samples were collected at 5-foot intervals with samples for VOCs collected as grab samples, and the remaining samples were composites of the entire 5-foot interval. Composite samples were analyzed for semi-VOCs and petroleum hydrocarbons. Ten percent of the composite samples were analyzed for metals.

One new source area was detected during the FSA-3 site investigation. When borehole SB-102 was drilled, contamination was detected with a PID and later confirmed by analytical results to be petroleum hydrocarbons. Investigation of the area found an abandoned 1942 aviation fuel pipeline that passed east

Table 1-56. Results of Soil-Gas Measurements Performed at the Fuel Saturation Area No. 3

Sample Location	TPH (ppm)	Sample Location	TPH (ppm)
W24-1	ND	U26-1	ND
W24-3	ND	U26-2	ND
W24-6	ND	U25-13 (4 feet)	ND
W25-1	ND	U25-13 (1.5 feet)	25
U25-1	ND	U25-15	ND
U25-3	ND	U25-9	ND
W25-3	ND	U25-11	ND
W25-5	100	T25-1	25
W25-4	ND	V24-1	30
W25-2	ND	V24-3	ND

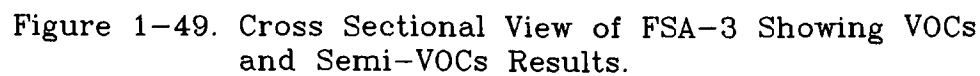
Note: ND is not detected.

of the borehole site (see Figure 1-48). The pipeline was marked on an old underground utility map but not on current maps of abandoned fuel lines in the area. Two more soil borings (SB-115 and SB-117) were drilled 50 feet on either side of the original boring and parallel to the 1942 pipeline. Both of these borings also indicated petroleum hydrocarbons although at lower levels. A soil boring (SB-113) was drilled on the east side of the pipeline and did not detect any contamination. This last soil boring was converted to a monitoring well (W-143). This area was not investigated further as contaminant levels were low (benzene at 74 $\mu\text{g/kg}$, xylene at 110 $\mu\text{g/kg}$), and levels dropped east of the line and in the adjacent borings.

Summary of Soils

A generalized cross section of the upper-zone sediments may be seen in Figure 1-49. Orientation of the section is from southwest to northeast and extends from the FSA-3 area to the JETS (see Figure 1-48).

The FSA-3 area appears to be located over a local bedrock high of Walnut Formation limestone with relief of 8 to 10 feet. The approximate extent and configuration of this bedrock structural high is shown in plan view on Figure 1-50. This structure-contour map of competent basement shows a north-trending elongated high in the FSA-3 area. The steeply-dipping eastern side of the high forms the western boundary of an apparent saddle which deepens toward Meandering Road to the north and also to the south-southeast in the direction of the Assembly Building. To the northeast of FSA-3 is a broad, low relief bedrock high positioned under the JETS. Competent Walnut limestone appears to immediately underlie unconsolidated Quaternary alluvium throughout the area with the exception of the western flank of the FSA-3 bedrock high. Boring SB-090 penetrated approximately 5 feet of a weathered Walnut shale, fossiliferous limestone, and a sandy conglomeratic unit lying directly on competent Walnut limestone bedrock.



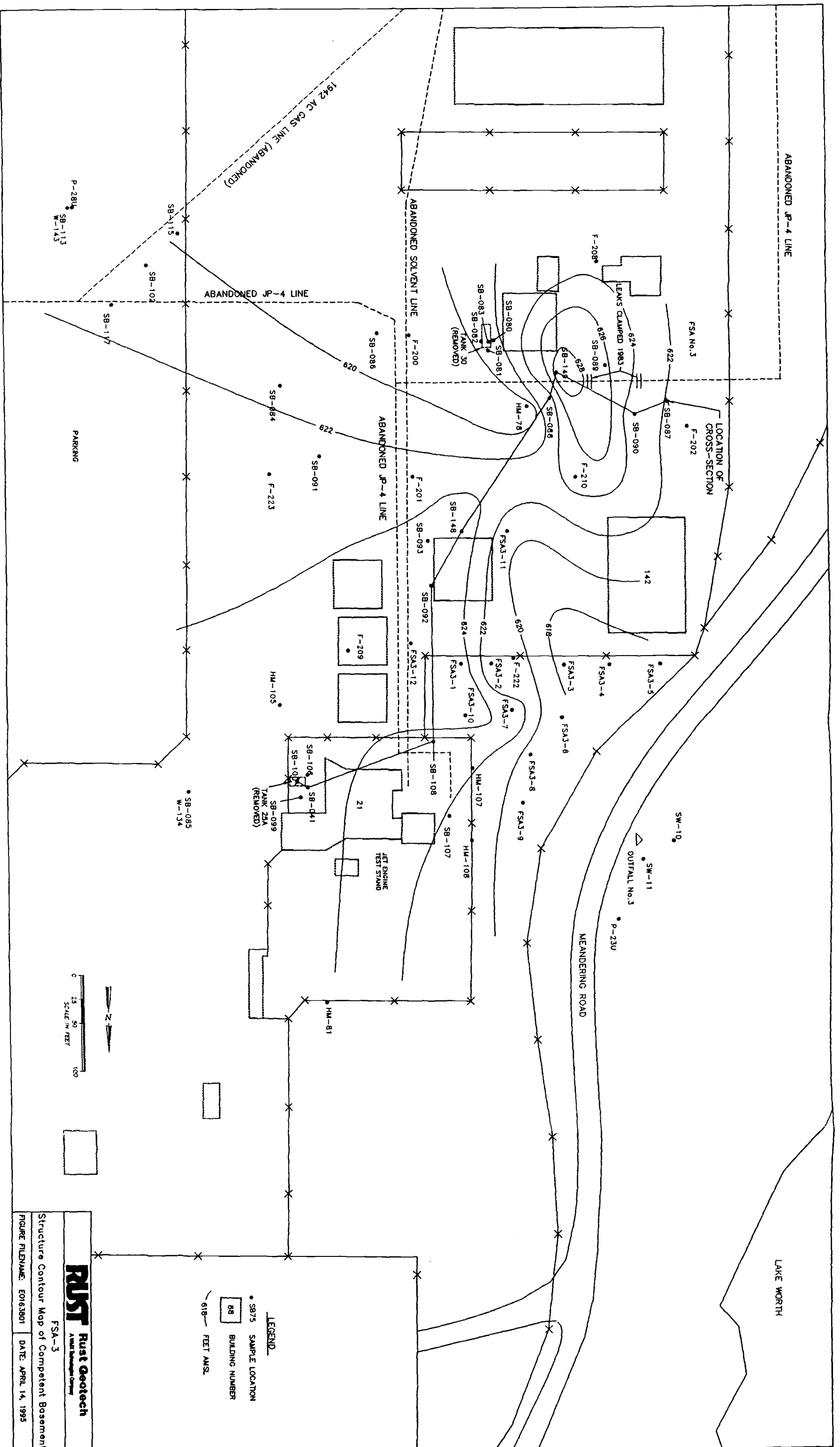


Figure 1-50. Structure Contour Map of Competent Bedrock Surface at FSA-3.

The upper-zone Quaternary sediments in the FSA-3 area are covered with up to 2 feet of concrete. The generalized stratigraphy of the Quaternary alluvium, as shown in Figure 1-49 and on the borehole logsheets in Appendix A-2 of the RI consists of 10 to 20 feet of brownish clay and silty-clay with occasional beds of fine-grained sand and poorly sorted gravels. Historical earth-moving activities have resulted in redistribution of the natural alluvium and placement of an unknown thickness of fill material at the surface. Interpreted fill material is shown in places on the cross section immediately below the concrete cover.

The UST-30 site, located southeast of FSA-3, contains four soil borings that were drilled to 10-to 13-feet total depth. The borehole logsheets, included in Appendix A-2 of the RI, depict mixed lithologies. All four borings encountered a sequence of interbedded clays, silts, sands, and gravels, with no clear correlation of units between the closely spaced boreholes. A possible explanation for this apparent rapid facies change is the proximity of the UST-30 site to a local bedrock high seen in Figure 1-50. UST-30 was located over the steep eastern flank of an erosional bedrock high that may have shed coarse debris that intermingled with fine-grained fluvial sediments.

Results of the Investigation

Several volatile and semivolatile fuel-related compounds were detected by laboratory analyses of soil samples from the FSA-3 area. Identified compounds common to JP-4 include 2-methylnaphthalene, naphthalene, benzene, ethylbenzene, and xylene. Maximum concentrations of these and additional detected organic compounds are found in Table 1-57, Table 1-58, and the Appendix E of the RI.

Figure 1-48 shows the extent of contamination of VOCs and semi-VOCs within the vadose zone of the FSA-3 area. There are three separate areas of contamination shown. The westernmost area sampled by SB-088, SB-090, and SB-149 had high levels of JP-4 related compounds at depths ranging from 2 to 15 feet within the vadose zone. The extent of contamination in the deeper vadose zone (10 feet to 15 feet) has been extended to the southeast to include the UST-30 area, where JP-4 related contamination was found at 13 feet in depth following excavation. Maximum concentrations of semi-VOCs, 2-methylnaphthalene (5,900 $\mu\text{g/kg}$) and naphthalene (2,700 $\mu\text{g/kg}$), were found in soils from 12 to 15 feet in depth in SB-088. Benzene, ethylbenzene, xylene, and JP-4 compounds, were found in boreholes SB-091 and SB-102, located to the east of the main FSA-3 area.

Figure 1-49 illustrates a cross-sectional view of the extent of contamination of VOCs and semi-VOCs in the FSA-3 area. Shown in this figure are the borehole sample intervals, areas of detected and inferred contamination, types of contamination (JP-4 or asphalt related), interpreted level of the water table, and an outline of generalized geology. JP-4 contamination found in SB-090, SB-149, and SB-088 appears to be from the adjacent fuel line that is suspected to have leaked. Areas of deeper contamination throughout the length of the cross section are interpreted to be associated with groundwater.

FSA-3 soil samples were also analyzed for TPH. Results of these analyses are shown on Figures 1-51 and 1-52, which illustrate the extent of TPH contamination in cross-sectional and plan view, respectively. The horizontal extent of TPH contamination (see Figure 1-52) appears to correlate with the location of fuel lines and UST-30. The blue colored contaminant envelope pertains to the higher concentrations of TPH (greater than 100 mg/kg), while the lower concentrations are designated by a red line. The maximum TPH concentration (945 mg/kg) is found in SB-088 and corresponds to JP-4

Table 1-57. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from FSA-3

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
2-Methylnaphthalene	(710)	5,900	80	11
Benzo(a)anthracene	(710)	1,800	80	1
Benzo(a)pyrene	(710)	930	80	1
Benzo(b)fluoranthene	(710)	1,800	80	1
Benzo(g,h,i)perylene	(710)	1,400	80	1
Benzo(k)fluoranthene	(710)	1,500	80	1
Bis(2-Ethylhexyl)phthalate	(710)	4,300	80	2
Chrysene	(710)	2,200	80	2
Fluoranthene	(710)	4,500	80	2
Indeno(1,2,3-cd)pyrene	(710)	1,500	80	1
Naphthalene	(710)	2,700	80	8
Phenanthrene	(710)	2,900	80	2
Pyrene	(710)	3,600	80	2

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, naphthalene, and 2-methylnaphthalene were identified in the Baseline Risk Assessment as chemicals of concern.

Table 1-58. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from FSA-3

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Ethylbenzene	(5)	960	81	10
Xylene	(5)	1,100	81	8
Acetone	(11)	220	81	63
Benzene	(5)	180	81	8
2-Butanone	(11)	190	81	11
Total Petroleum Hydrocarbons	(10) mg/kg	945 mg/kg	78	38

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

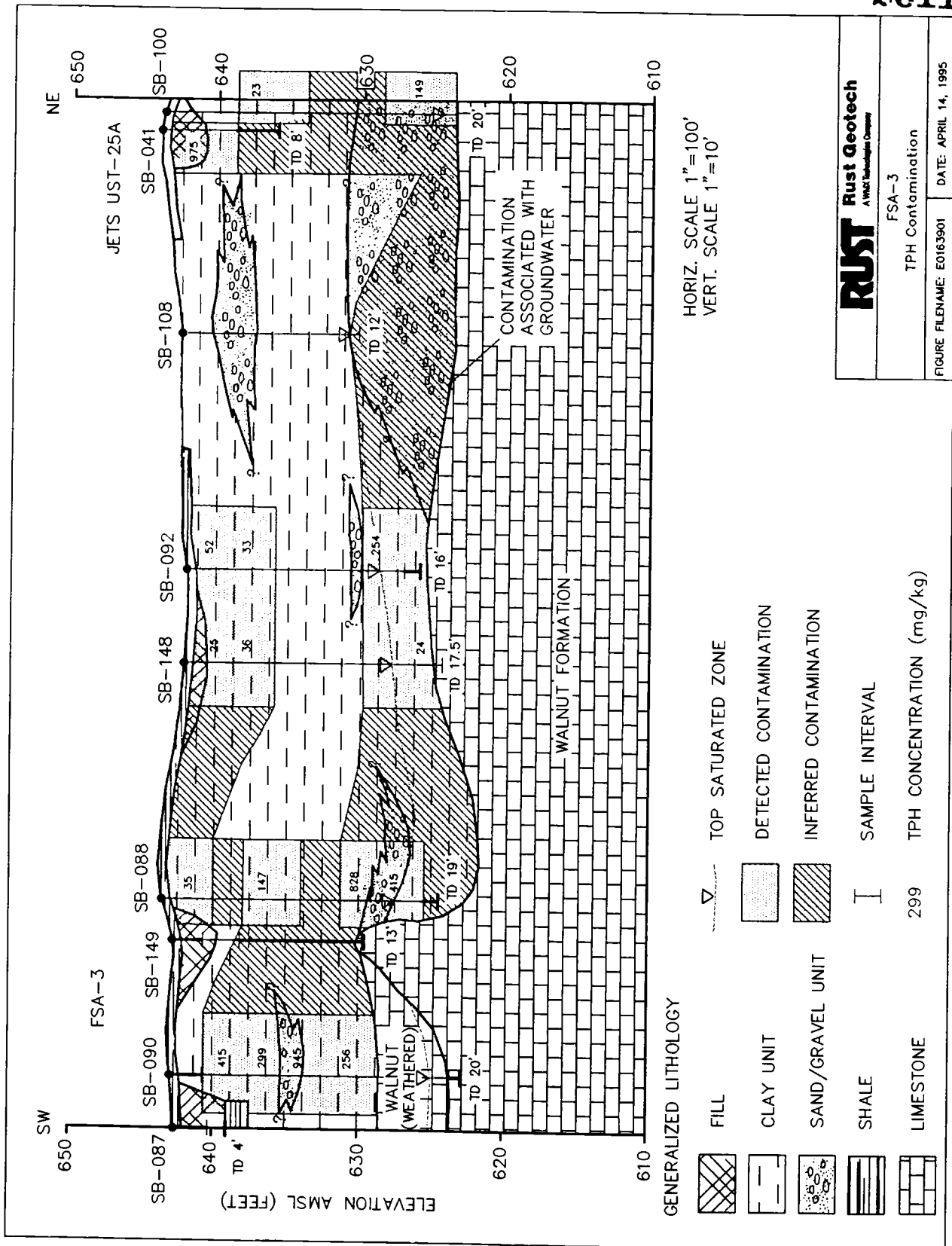


Figure 1-51. Cross Sectional View of FSA-3 Showing TPH Results.

Figure 1-52. Extent of TPH in the Vadose Zone Detected at FSA-3.

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contamination suspected to have leaked from the adjacent fuel line. Relatively low levels of TPH in the FSA-3 area (red line envelopes) may be attributed to minor fuel line leaks, spills of fuels from surface activities, asphalt contamination, or a combination of these potential sources. The vertical extent of TPH contamination (see Figure 1-51) corresponds well with that for VOCs and semi-VOCs. The reported levels of TPH are posted adjacent to boreholes on the cross section. Zones with high levels of TPH correlate well with identified areas of JP-4 contamination.

The levels of metals found in FSA-3 soil samples are within the range for background soil of the western United States. (see Table 1-59).

Table 1-59. Summary of Inorganic Analytical Results for Soil Samples Obtained from FSA-3

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for the Western USA
Antimony	(8.6)	(13.3)	2.2	15	0
Arsenic	2.6	7.1	21.6	15	0
Beryllium	0.3B	1.2B	3.6	15	0
Cadmium	(0.89)	1.7	2.8	15	0
Chromium	5.3	17.2	196.6	15	0
Copper	(1.8)	7.8	90.0	15	0
Lead	3.7	(13)	55.1	15	0
Nickel	(5.7)	11.9	66.2	15	0
Selenium	(0.45)	(2.3)	1.4	15	0
Silver	(0.74)	(0.98)	1.4	15	0
Thallium	(0.43)	(0.49)	0.8	15	0
Zinc	11.6	29.2	176.2	15	0

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

Toxicity Characteristic Leaching Procedure Analytical Results (TCLP)

The EPA TCLP was used to analyze for VOCs, semi-VOCs, and inorganic constituents for sample SB-149-01, obtained 2- to 4-feet below ground level. Analysis of the liquid TCLP extract indicated all inorganic constituents, except barium, were reported below detection limit. Barium was detected at a concentration of 1,750B µg/L, a value that is less than the 100,000 µg/L regulatory limit. All VOCs and semi-VOC analytes were below detection limit.

Conclusions

Significant contamination from JP-4 related compounds was found in soils from the FSA-3 area. The highest levels of contamination occur in SB-088, near the suspected location of leakage from an underground fuel line. This westernmost source area is believed to be the main contributor to the widespread groundwater contamination with floating product found to exist in the FSA-3 area. Two additional areas of fuel-related contamination were identified to the east of the main FSA-3 area. These areas were penetrated by boreholes SB-091 and SB-102. The sources for these areas of contamination are likely to be minor leaks of fuel lines or fuel-related activities at the surface.

Estimates of the volume of contaminated material in the vadose zone have been calculated for the individual areas described. The volume was derived by using the approximate width, length, and thickness of the areas shown on Figure 1-48. Area A (SB-090, SB-149, SB-088, and 6-501B) contains an estimated 5,200 cubic yards of soil that is contaminated with JP-4. The remaining two areas, B (SB-091) and C (SB-102), have estimated volumes of 700 and 500 cubic yards, respectively. The total estimated volume of soil contaminated with TPH as shown in Figure 1-52 is approximately 40,000 cubic yards. However, the estimated volume of contamination greater than 100 ppm is 5,200 cubic yards for Area A. The remaining TPH contamination is less than 100 ppm.

1.5.3.14 Former Fuel Storage Area

Summary of Investigations

Previous Investigations: A 100,000-gallon above-ground JP-4 storage tank was located at the southwest corner of Plant 4 near the center of the Radar Range (see Figure 1-53). In use from the early 1940s to 1962, the storage tank was suspected to have leaked. The tank was removed from the site and relocated in 1962. Soil beneath the tank was reportedly observed to be saturated with jet fuel at the time of removal (Hargis & Montgomery 1983). Hargis & Montgomery reports that the buried pipeline transporting fuel from the area leaked on several occasions. This site is identified as the FFSA.

Hargis & Montgomery drilled one test hole (TH-9) and one monitoring well (HM-8) in December 1982, under the previous site of the fuel tank (Figure 1-53). No contamination was detected in TH-9. HM-8 soil samples were collected from four depth intervals and analyzed for trace metals, cyanide, organic compounds, oil and grease, and jet fuel. No significant trace metals or cyanide were detected. Relatively low levels of VOCs, semi-VOCs, and oil and grease were found in HM-8 soil samples taken from the surface to a depth of 26 feet (Hargis & Montgomery 1983). The primary contaminants found include oil and grease (149 mg/kg), methylene chloride (200 µg/kg), and di-n-butyl phthalate. Removal of the soils was not reported.

Current Investigation: Four soil borings (SB-074, SB-075, SB-076, and SB-077) were drilled 25 feet north, south, east, and west, respectively, of monitoring well HM-8 (Figure 1-53) to determine the lateral and vertical extent of contamination. SB-074 and SB-075 were drilled from the surface to the top of the water table with samples collected in 5-foot intervals. SB-076 and SB-077, upgradient of the site, were drilled and sampled to 16 feet. Samples for VOCs were grab samples from each 5-foot interval. Other samples were composited over each 5-foot interval. Composite samples were analyzed for fuel hydrocarbons and oil and grease.

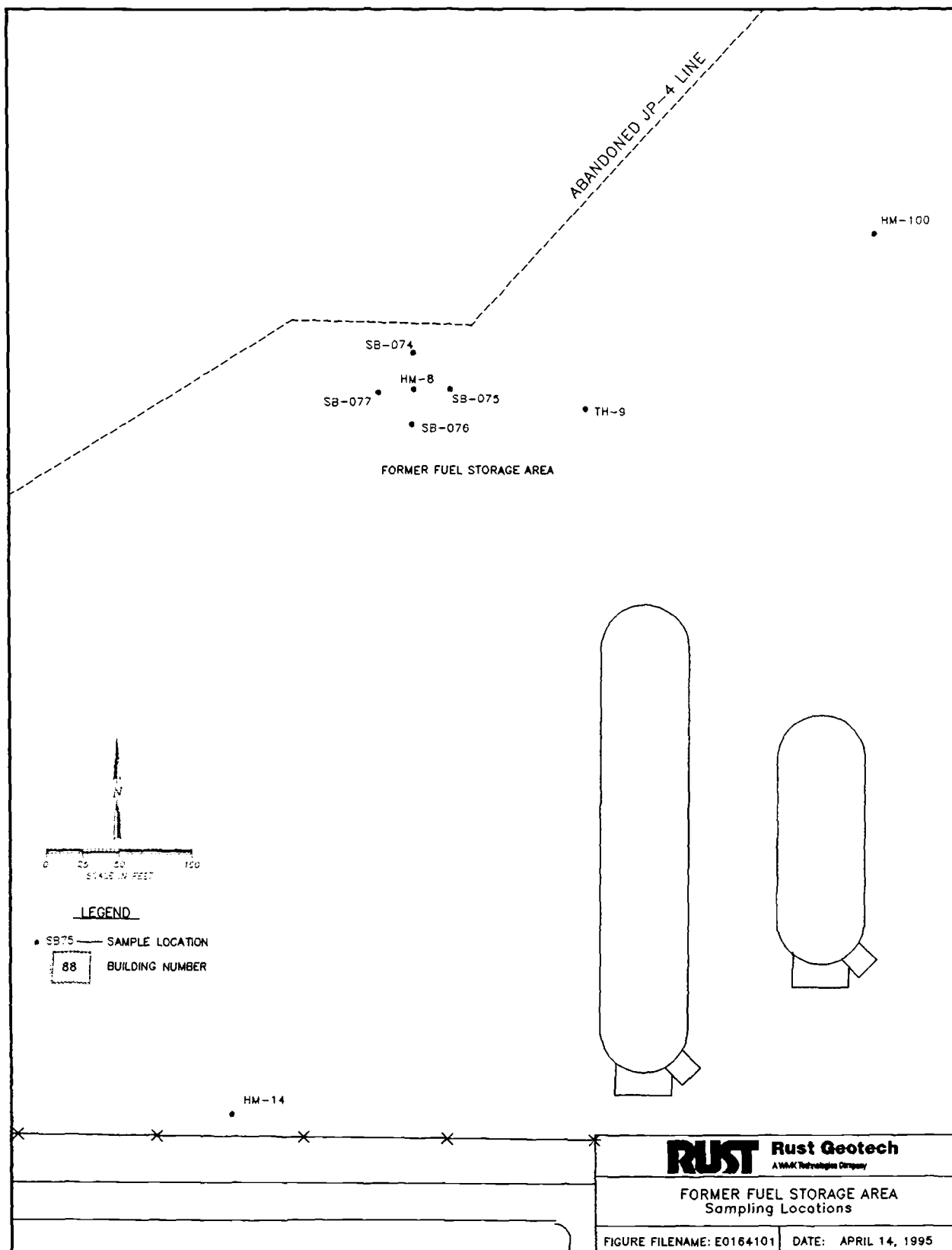


Figure 1-53. Borehole Soil Sample Locations at the Former Fuel Storage Area.

Summary of Soils

Limestone of the Walnut Formation was found at 49 feet below surface in monitoring well HM-8, drilled near the center of FFSA. The recent borings were drilled to depths of 16 feet to 38 feet and failed to reach bedrock. The lithologic sequence encountered may be generalized as silty clays interbedded with 1- to 4-foot thick lenses of limestone gravel and stringers of fine-grained silty sands. Description of the soils encountered may be found on the borehole logsheets in Appendix A-2 of the RI.

Results of the Investigation

Few organic contaminants were detected by analyses of the FFSA samples (see Table 1-60, Table 1-61, and the Appendix E of the RI). Low levels of TPH (67 mg/kg) and oil and grease (24 mg/kg) were detected in FFSA soil samples (see Table 1-60). Bis(2-ethylhexyl)phthalate, a common lab contaminant, was detected in concentrations up to 1,900 µg/kg in soil samples from SB-075 (see Table 1-61). However, bis(2-ethylhexyl)phthalate was also detected in associated laboratory blanks.

Table 1-60. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from FFSA

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Acetone	(11)	12	24	1
Oil and Grease	24 mg/kg	24 mg/kg	23	1
Total Petroleum Hydrocarbons	(10) mg/kg	67 mg/kg	23	2

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Table 1-61. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from FFSA

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Bis(2-ethylhexyl)phthalate	(710)	1900	29	5

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Conclusions

No significant concentrations of chemicals of concern or other contaminants were found by the sampling and analyses. This evidence suggests that soil previously reported as saturated with jet fuel was removed from the site.

1.5.3.15 Jet Engine Test Stand (JETS) and UST Site 25A

Summary of Investigations

Previous Investigations: The JETS site, located northeast of Facilities Building No. 142 and east of Meandering Road (see Figure 1-54), was identified by Radian (1987) during the IRP Phase II investigation as a site containing fuel-related contamination in soil and groundwater. The site is located north of a fuel test area and a known area of fuel contamination (FSA-3). Facilities Building No. 21 near the site has a sump, constructed in 1975, that collects water for cooling, noise suppression, and building cleanup, and pumps it to an industrial waste line. Adjacent to the site and Building No. 21 is UST Site 25A which consisted of two vertical underground tanks once used for fuel storage. Just to the north of the JETS is an active underground JP-4 tank. There appear to be several possible sources for contamination at the JETS. Both the sump and the abandoned tanks were suspected sources of contaminants. Soil samples collected from five borings in the vicinity of the JETS contained anomalous concentrations of fuel hydrocarbons and oil and grease. Groundwater samples collected from four monitoring wells in the vicinity of JETS indicated that two of the wells contained fuel-related hydrocarbons (HM-107 and HM-108).

Three monitoring wells (HM-105, HM-107, and HM-108) and two soil borings (SB-9 and SB-10) were installed by Radian near JETS in August 1986 (see Figure 1-54). Soil samples were collected and analyzed for hydrocarbon fuels and oil and grease. Hydrocarbon fuels (1,700 mg/kg) were found in soils from HM-107 at a depth of 14 to 15 feet. Oil and grease were detected at HM-107 and SB-9.

UST Site 25A tanks were removed prior to December 22, 1988, which was the effective date of Federal Subtitle I regulations. After removal of the tanks, soil samples were collected at a depth of 10 feet from five sampling locations. The soil was found to be contaminated with benzene, toluene, and xylene. The removed tanks had fist-sized holes in them (Hargis + Associates 1989). The pipeline supplying the tanks also leaked. No soil was removed.

Current Investigation: Additional soil borings and soil samples were needed at the site to better define the extent of contamination. During the current investigation seven soil borings were drilled around the JETS area. SB-041, SB-099, SB-100, and SB-106 were drilled to investigate the former underground tanks (UST site 25A) next to Building 21, the JETS. SB-107 and SB-108 were drilled immediately west of JETS and SB-085 east of Building 21 was completed as monitoring well W-134.

Soil borings were drilled and sampled around the perimeter of JETS. Soil borings and monitoring well data from a prior investigation (Radian 1987) were used on the west and north side. The Geotech borings were sampled in 5-foot intervals from the surface to the top of the water table. A grab sample for VOCs was taken from each interval. The remaining sample was a composite of each 5-foot interval. Composite soil samples were analyzed for semi-VOCs, petroleum hydrocarbons, and oil and grease.

Summary of Soils

Figure 1-55 is a generalized geologic cross section that is oriented southwest-northeast and extends from the FSA-3 area to JETS. The upper-zone sediments depicted in the cross section and borehole logsheets consist of up to 14 feet of silty clay with occasional sand and gravel intervals and traces of black organic material. Soil borings in the vicinity of the removed UST Site 25A tanks encountered a

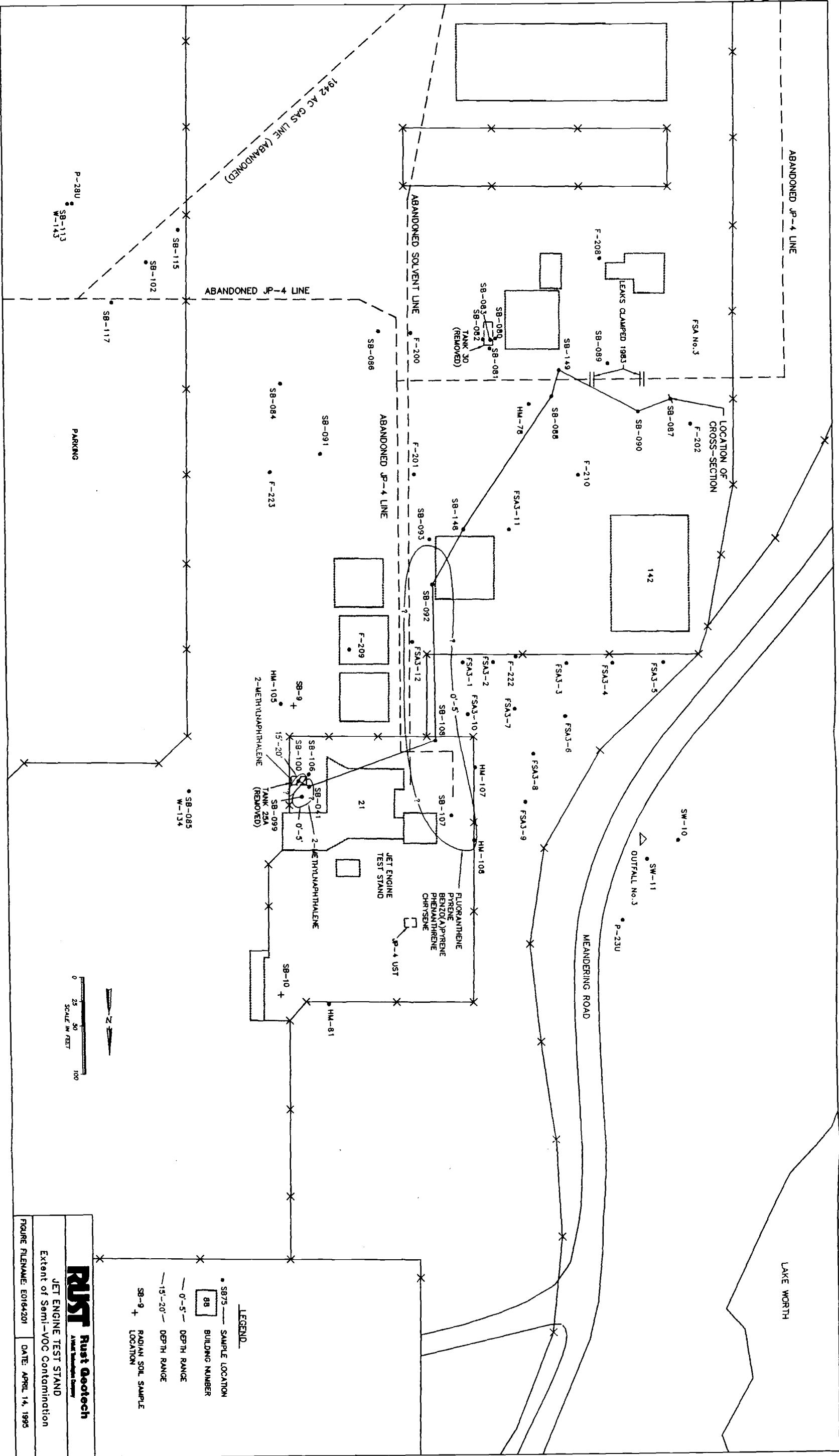


Figure 1-54. Extent of Semi-VOCs Detected at the Jet Engine Test Stand.

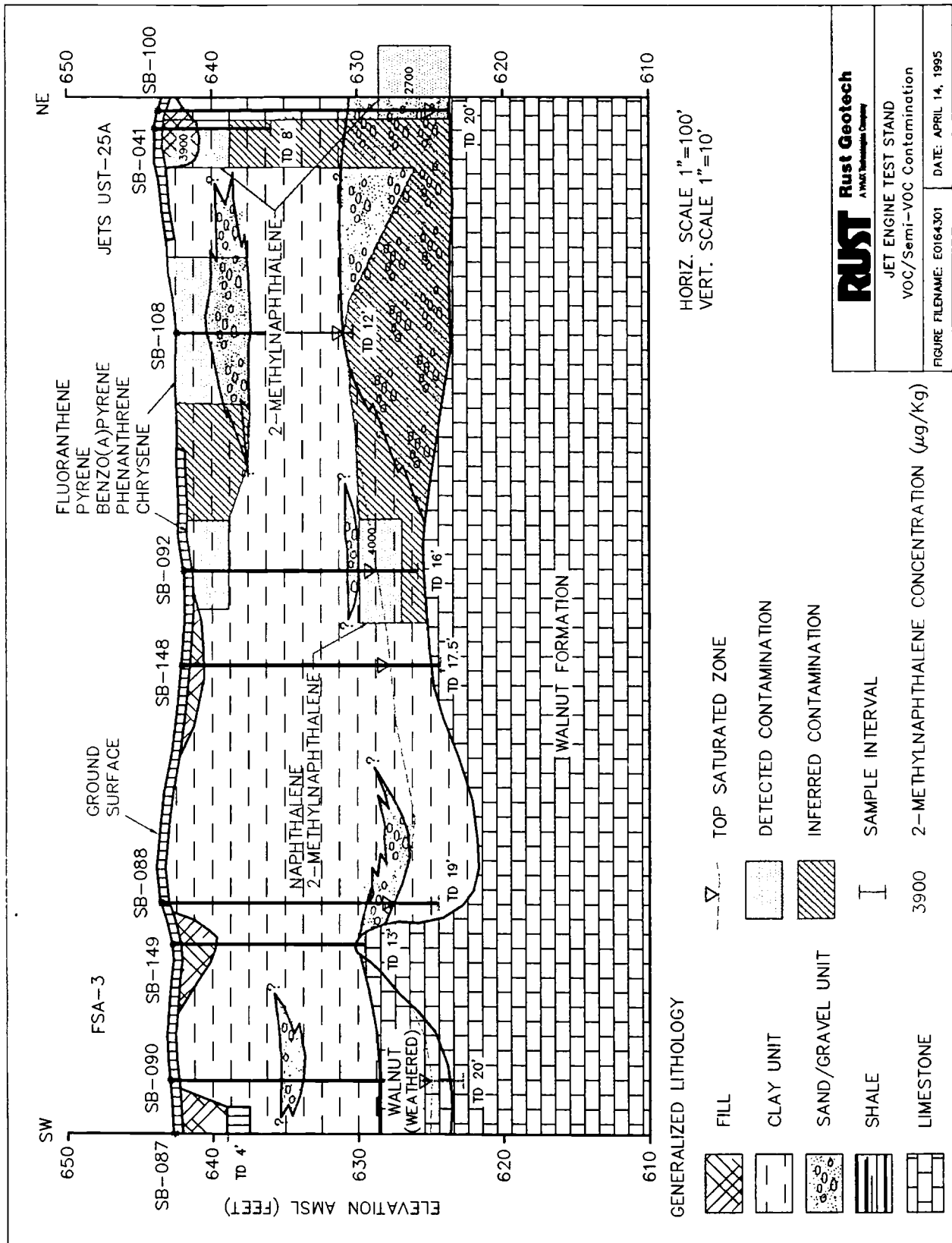


Figure 1-55. Cross Sectional View Showing VOCs and Semi-VOCs Detected at the Jet Engine Test Stand.

1- to 7-foot thick basal unit of limestone gravels and sand that rests directly on Walnut Formation limestone found at 18.7 feet below surface. Competent gray limestone bedrock was reached in SB-106 at 18.7 feet below surface. In some areas, as shown on the cross section, the Quaternary alluvium is covered by concrete pavement and a variable thickness of fill material. JETS is positioned on the flank of a low relief bedrock erosional high.

Results of the Investigation

Sample results from three soil borings drilled around the perimeter of JETS and four located at UST Site 25A are summarized in Table 1-62, Table 1-63, Table 1-64, and the Appendix E of the RI.

Table 1-62. Summary of Semi-VOC Analytical Results for Soil Samples Obtained from JETS and UST Site 25A

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
2-Methylnaphthalene	(740)	3,900	18	2
Benzo(a)Anthracene	(740)	1,800	18	2
Benzo(b)Fluoranthene	(740)	1,400	18	1
Benzo(g,h,i)Perylene	(740)	1,300	18	1
Benzo(k)Fluoranthene	(740)	1,100	18	1
Chrysene	(740)	1,700	18	2
Fluoranthene	(740)	5,100	18	2
Indeno(1,2,3-cd)Pyrene	(740)	1,100	18	1
Phenanthrene	(740)	5,000	18	2
Pyrene	(740)	3,700	18	2

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, and 2-methylnaphthalene were identified in the Baseline Risk Assessment as chemicals of concern.

Table 1-63. Summary of VOC and TPH Analytical Results for Soil Samples Obtained from JETS and UST Site 25A

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Acetone	(11)	200	19	14
2-Butanone	(11)	67	19	4
Ethylbenzene	98	98	19	1
Total Petroleum Hydrocarbons	(10) mg/kg	975 mg/kg	19	9

Table 1-64. Summary of Inorganic Analytical Results for Soil Samples Obtained from JETS and UST Site 25A

Analyte	Minimum mg/kg	Maximum mg/kg	Upper Background Limit (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for Western USA
Antimony	(8.8)	(9.4)	2.2	8	0
Arsenic	2.7	4	21.6	8	0
Cadmium	(0.88)	1.4	2.8	8	0
Chromium	4.5	14.1	196.6	8	0
Copper	(1.8)	9.7	90.0	8	0
Lead	3.3	12	55.1	8	0
Nickel	(5.5)	9.7	66.2	8	0
Selenium	(0.45)	(2.2)	1.4	8	0
Silver	(0.88)	(0.94)	1.4	8	0
Thallium	(0.44)	(0.47)	0.8	8	0
Zinc	11.9	32	176.2	8	0

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.

Two semi-volatile chemicals of concern, fluoranthene and pyrene, were detected in the shallow samples from SB-107 and SB-108. Maximum concentrations for fluoranthene (5,100 $\mu\text{g/kg}$), pyrene (3,700 $\mu\text{g/kg}$), and phenanthrene (5,000 $\mu\text{g/kg}$) were found in SB-107. The semi-VOC contamination found in SB-107 and SB-108 extends south and includes SB-092. An outline of the extent of contamination is shown in Figure 1-54. Figure 1-55 illustrates the vertical extent of contamination in boreholes SB-041, SB-092, and SB-108.

Significant levels of 2-methylnaphthalene were found in three of four boreholes drilled at the UST Site 25A. A maximum concentration of 3,900 $\mu\text{g/kg}$ 2-methylnaphthalene was found in the shallow sample (0 to 5 feet) of SB-041. The extent of contamination in the vadose zone is defined by SB-041 and SB-099 and shown in Figure 1-54. The cross section in Figure 1-55 shows the contamination in SB-041 which is interpreted to extend to the groundwater zone where 2-methylnaphthalene was detected in the saturated soil zone of SB-100.

TPH were detected in all boreholes at UST Site 25A. Low concentrations (17 to 21 mg/kg) of TPH were detected in SB-085 from sample depths of 2 to 18 feet. The horizontal and vertical extent of TPH contamination is shown in Figures 1-56 and 1-57. There appears to be a good correlation between the relative levels of TPH and 2-methylnaphthalene. Ethylbenzene (98 $\mu\text{g/kg}$) was detected in the top 5 feet of SB-041.

Concentrations of metals are within the range for background soils of the western United States.

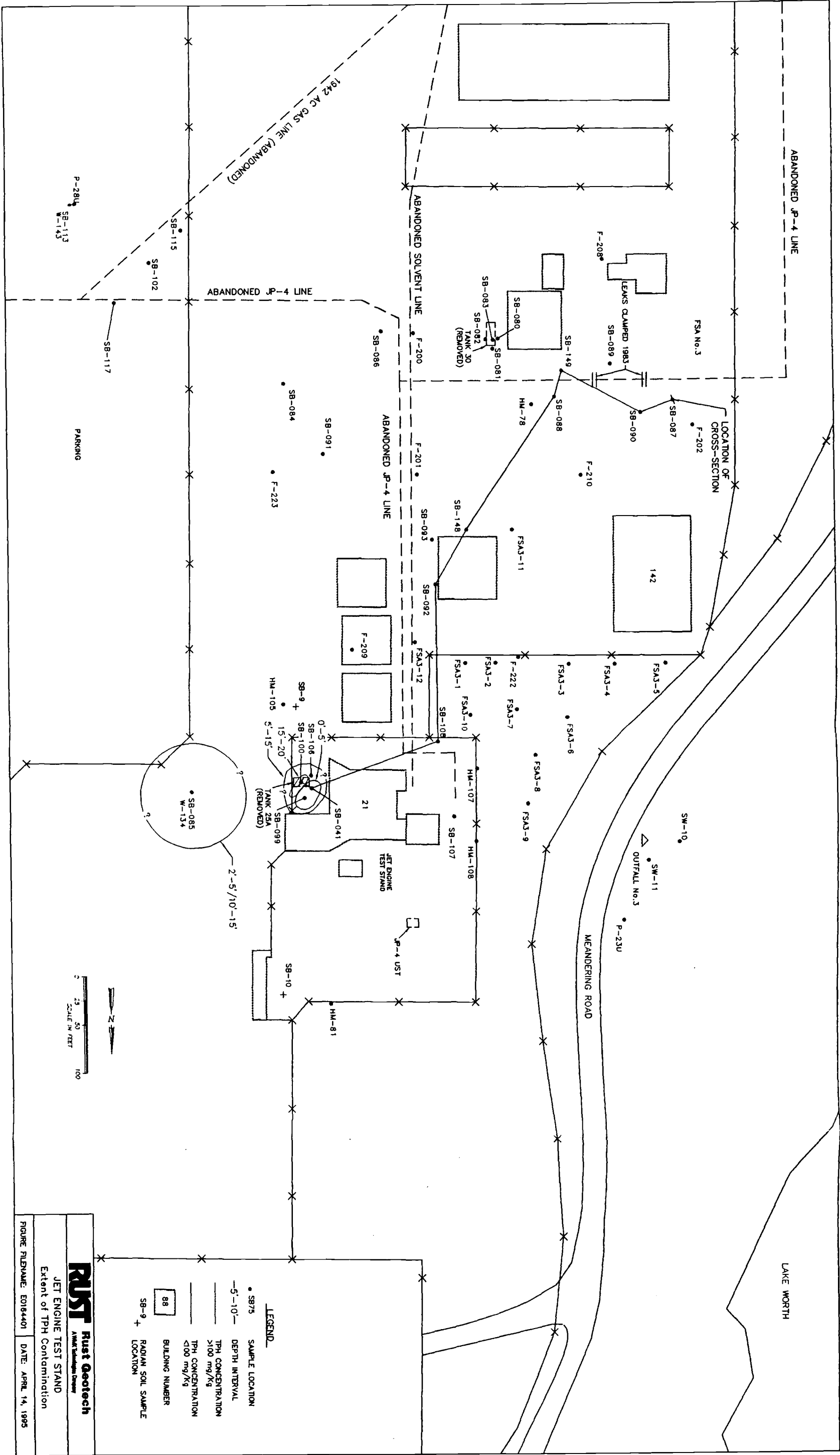


Figure 1-56. Extent of TPH Detected at the Jet Engine Test Stand.

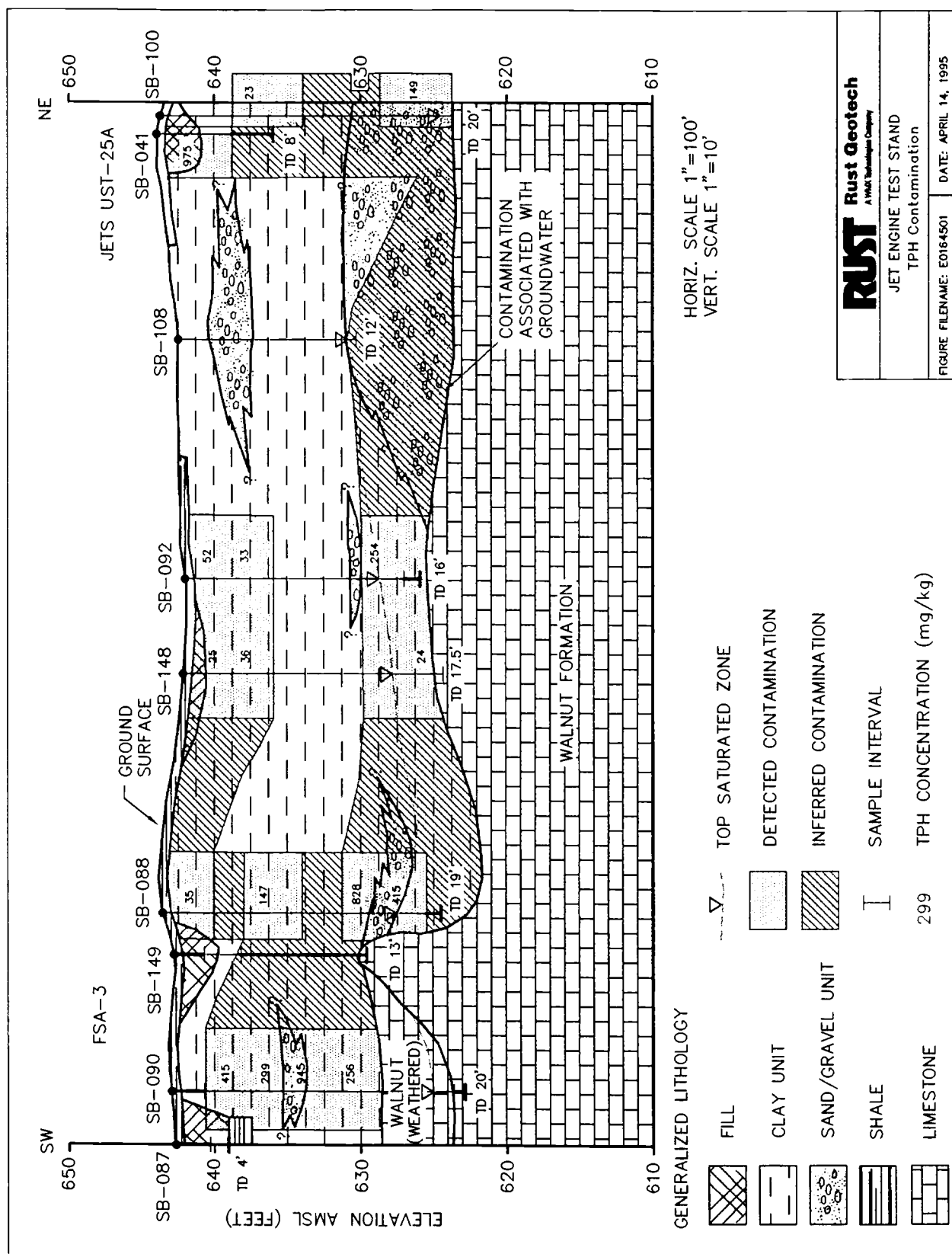


Figure 1-57. Cross Sectional View Showing TPH Detected at the Jet Engine Test Stand.

The north trending elongated envelope located to the west of JETS reflects shallow contamination (0 to 5 feet) detected in soil samples from SB-092, SB-108, and SB-107. Chemicals found in this area include fluoranthene, pyrene, benzo(a)pyrene, phenanthrene, and chrysene. All of these contaminants are coal-tar derivatives and are not commonly found in jet fuel. The coal-tar association coupled with the shallow depth of detection suggest that this contamination is related to asphalt. An estimate of the volume of contaminated material in the vadose zone is approximately 3,000 cubic yards.

The other area of significant contamination in the vadose zone is associated with the removed UST Site 25A. The extent of fuel-related contamination is shown in Figure 1-54, and the volume of material is approximately 100 cubic yards.

1.5.3.16 Waste Water Collection Basins (WWCB)

Previous Investigations

The waste water collection basins (WWCB), located south of the Process Building (Facilities Building No. 181) (see Figure 1-58), consist of two lined, concrete waste basins, each with an approximate capacity of 85,000 gallons, designed to collect and settle suspended solids from plant waste water. Processed water is then discharged to the Fort Worth sewer system. IRP Phase I investigations determined that several spills from vapor degreasers in the Process Building (primarily TCE) have flowed to the basins via floor drains that empty into the waste water collection basins. Other chemical spills may have entered the basins via the floor drains. The integrity of the liner coating the concrete basins had not been evaluated for several years. It is suspected that cracks in the basin floor or wall may allow contaminants to leak to the surrounding soils.

Groundwater samples from monitoring well HM-47 east of the basins, indicate that the groundwater is contaminated with VOCs. It is uncertain whether the VOCs in the groundwater at this location can be attributed to the waste water basins. The presence of TCE in the groundwater indicates that the source is related to the Process Building (vapor degreaser spills). A sanitary sewer line runs on an east-west line under the site, and a storm drain, which runs northwest-southeast, is approximately 75 feet south of the basins.

The drilling log from HM-47 shows clayey silt or sandy clay to 16 feet, then sand and gravel to bedrock. No soil samples were analyzed. Intellus Corp. drilled two soil borings, FB-5 and FB-6, in the area of suspected Chrome Pit No. 2, approximately 100-feet west of the WWCB. Both borings found undisturbed soils at a depth of 2 feet. Soils were generally sandy silts with a sandy gravel zone at about 14 feet. A field PID was used to screen soil every half-foot. No response above background was noted. Laboratory analysis for total chromium and barium indicated background levels. Both borings terminated above water level.

Current Investigation

Solvent and other chemical spills may potentially enter the basins and through leakage enter soils. To evaluate whether the basins have been a source of TCE and other contaminants, additional subsurface soil sampling and upper-zone groundwater sampling was needed both upgradient and downgradient of the

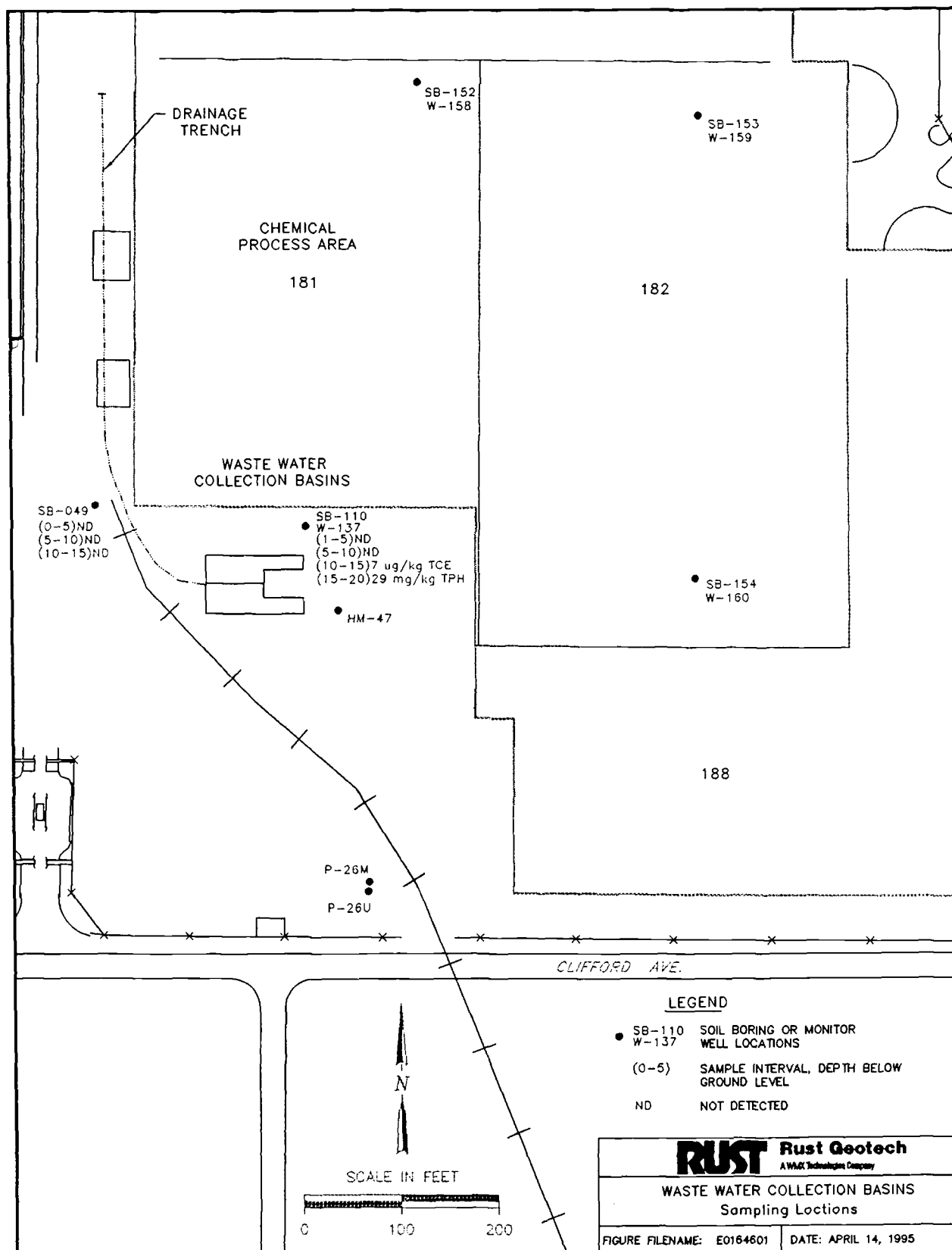


Figure 1-58. Borehole Soil Sample Locations at the Waste Water Collection Basins.

basins. The initial objective of the data collection in the basins area was to determine if the basins are a source of contamination or if the source exists upgradient of the basins. In addition, a visual inspection of the integrity of the basin walls and floor was made to determine if significant leakage may be occurring from these basins.

One soil boring (SB-110) was drilled immediately north and east (downgradient) of the WWCB. The location for this boring was based on groundwater contour maps from a prior investigation (Hargis + Associates 1989). The boring was drilled to the top of the water table with soil samples collected from 5-foot intervals. A second soil boring, SB-049, was drilled west of the WWCB (upgradient) and sampled for the same analytes. Samples for VOCs were grab samples from each 5-foot interval; the remaining samples were composites of each interval. Composite samples were analyzed for semi-VOCs, TPH, and metals. SB-049 was drilled through silty clay with little sand or gravel and encountered bedrock at 15 feet. SB-110 was drilled through silty clay to 16 feet, then clayey sands, sands, and gravels until bedrock at 29 feet. (Appendix A-2 of the RI)

Results of the Investigation

Analytical results from the two borings do not show elevated levels of organic or inorganic contaminants. Low amounts of TCE (7 $\mu\text{g/kg}$) were reported in SB-110 at the 10- to 15-foot depth and 29 mg/kg of TPH were reported at the 15- to 20-foot depth interval (see Table 1-65).

Table 1-65. Summary of VOC and TPH Analytical Results for the Waste Water Collection Basins

Analyte	Minimum $\mu\text{g/kg}$	Maximum $\mu\text{g/kg}$	No. of Samples Analyzed	No. Above CRQL
bis(2-ethylhexyl) phthalate	(750)	1,300	11	1
Trichloroethene	(5)	7	11	1
TPH	(10) mg/kg	29 mg/kg	11	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 2) TCE was identified by the Baseline Risk Assessment as a chemical of concern.

Inspection of the WWCB

A TCE leak in the process building was reported by GD in June 1991. TCE had leaked from a tank and through the drain system into the WWCB. Contaminated water and sludge from the basins was pumped into portable tanks for treatment and the basins were cleaned. While the basins were empty, a visual examination of the basin walls and floors was made on June 15-16, 1991. The concrete appeared in good shape, with no cracks. The liner was missing over large areas of the floor (60 percent gone on the north basin floor) and was cracked in places on the walls. The floor of the south basin was not examined by Geotech personnel but GD personnel stated the south basin had less liner over the floor than the north. No cracks were evident on the south basin. The concrete behind the liner could not be examined. As the basins were being refilled from a fire hose, the water from the hose was washing

sections of the liner off the concrete ramp, which would indicate the liner is not bonded to the concrete effectively. The drainage trench system on the outside of the Building, leading to the WWCB, was also examined and several small sections of the concrete trench were observed to be open to the soil where the concrete had been etched by acids. The trench is more likely to allow contamination to pass through to the underlying soils than are the WWCB. The trench sections open to the soil were near the north end of Building 181 and would not contribute to soil contamination adjacent to the WWCB.

Conclusions

SB-049 sample results did not indicate soil contamination. Also, it should be noted that SB-049 was drilled at the suspected location of Chrome Pit No. 2 and did not indicate elevated levels of contaminants that may have been related to that area. Samples collected from SB-110 had only minor amounts of contamination at depths of 10 to 15 feet (TCE - 7 $\mu\text{g/kg}$) and 15 to 20 (TPH - 29 mg/kg). Soil sample results from these boreholes do not indicate soil contamination in the vicinity of the WWCB.

1.5.3.17 Other Source Areas

A variety of contaminant sources exist at Plant 4. Because the plant has been in continuous operation since 1942, significant quantities of contaminants may have been released to the environment from past disposal practices, fire training activities, numerous leaks in buried fuel lines, process lines and tanks, or spills. The sites previously identified in this section appear to be the major contributors to the contaminants already observed in contaminant pathways.

Because there are numerous sources of contaminants, it should be noted that many areas of Plant 4 will potentially contain a mixture of contaminants from several source areas.

One new source area was detected during the FSA-3 site investigation. The SAP called for one monitoring well to be placed east (upgradient) of the FSA-3 site to aid in determining groundwater flow direction. When the borehole, SB-102, was drilled, contamination was detected with PIDs and later confirmed by analytical results to be petroleum hydrocarbons. At 17 feet to 20 feet, benzene, ethylbenzene, and xylene were detected at concentrations of 14, 74, and 64 $\mu\text{g/kg}$, respectively. At 20 to 23 feet in depth the concentrations were 16, 82, and 110 $\mu\text{g/kg}$. No TPH was detected in the 17- to 20-foot sample, but the 20- to 23-foot and 23- to 26-foot samples were 58 and 13 mg/kg , respectively. Inorganic and semi-VOC results for SB-102 were very low or below the detection limit. Investigation of the area revealed an abandoned 1942 aviation fuel pipeline that passed east of the borehole site. The pipeline was marked on an old underground utility map but not on current maps of abandoned fuel lines in the area. Two more soil borings, SB-115 and SB-117, were drilled 50 feet on either side of the original boring and parallel to the 1942 pipeline. Both of these borings also indicated petroleum hydrocarbons, although at lower levels. A soil boring was drilled on the east side of the pipeline and did not detect any contamination. This last soil boring was converted to a monitoring well (W-143). This area was not investigated further as contaminant levels were low (benzene at 74 $\mu\text{g/kg}$, xylene at 110 $\mu\text{g/kg}$), and levels dropped east of the line and in the adjacent borings.

No additional source areas were discovered during the current investigation, which concentrated on the previously identified sites.

1.5.4 Sediment Contamination

1.5.4.1 Lake Worth Sediment Sampling

Introduction

Contaminants from Plant 4 may be entering Lake Worth via surface water drainage and upper-zone groundwater discharge. Because Lake Worth is a source of public water supply and is also a source of recharge to the Paluxy Aquifer, additional data were needed to evaluate the potential risk to human health and the environment from contaminants in the sediments of Lake Worth. Sediment samples were collected from the lake bottom in areas where contamination was most likely to be found to determine if past contaminant spills or releases have reached Lake Worth. The data from the samples were used to assess potential risk associated with contaminated sediments.

Samples were collected from sediments in areas where contamination was likely to be found based on surface drainage patterns. These areas included outfalls, tributaries, and areas adjacent to known hazardous waste sites. Sampling locations and the type of sample analysis performed were selected in agreement with United States Department of the Interior, Fish and Wildlife Service (USFWS) and the EPA Region VI personnel.

A total of 25 locations, including one location in Meandering Road Creek and one location in the drainage above the lake background location (see Figure 1-59), were sampled for the Lake Worth investigation. Six coves of Lake Worth with drainage originating at Plant 4 were sampled, with samples collected from three locations at each cove. One sample was taken 10 feet from shore at the head of the cove, adjacent to the drainage, and two more samples were taken evenly spaced out toward the middle of the cove. Three locations were sampled offshore from the Nuclear Aerospace Research Facility (NARF) area, and one location was sampled off the north shore of the site. The maximum depth of sample that could be taken was 17 feet, which was the length of the sampling device. Samples were collected from the lake bottom to 22 inches below the lake bottom, the length of the sampler, and split into two 11-inch samples for analysis. The sampler was returned to the bottom several times to gather sufficient material for composite samples. If the sample was gravelly or very sandy, it was thrown out and a new sample collected that contained a greater amount of sediment (silt or clay).

The type of analysis performed was dependent on the sampling location (see Table 1-66), with some sites having special analysis, such as radioisotope analysis for NARF area samples. Seven samples were analyzed for VOCs, semi-VOCs, oil and grease, TPH, and metals. VOC samples were bottled immediately from the sample barrel, and the remainder of the material was composited for other analyses. Samples collected from the drainage near the NARF area were also analyzed for radioisotopes. A field scan was performed for alpha, beta, and gamma radiation on all samples collected from sediments near the former NARF site, with no radiation levels above background detected. Twenty-one samples were analyzed for polynuclear aromatic hydrocarbons (PAHs) and three were analyzed for polychlorinated biphenyls (PCBs) and pesticides. A background sediment sample was collected at a location 0.5 mile west of the Lockheed Lake Worth pumping station and was analyzed for all analytes except selected metals (aluminum, cadmium, chromium, nickel, lead).

Tissue sample collection from the lake and creek sampling locations and analyses are discussed in Section 1.5.7, "Ecological Tissue Contamination."

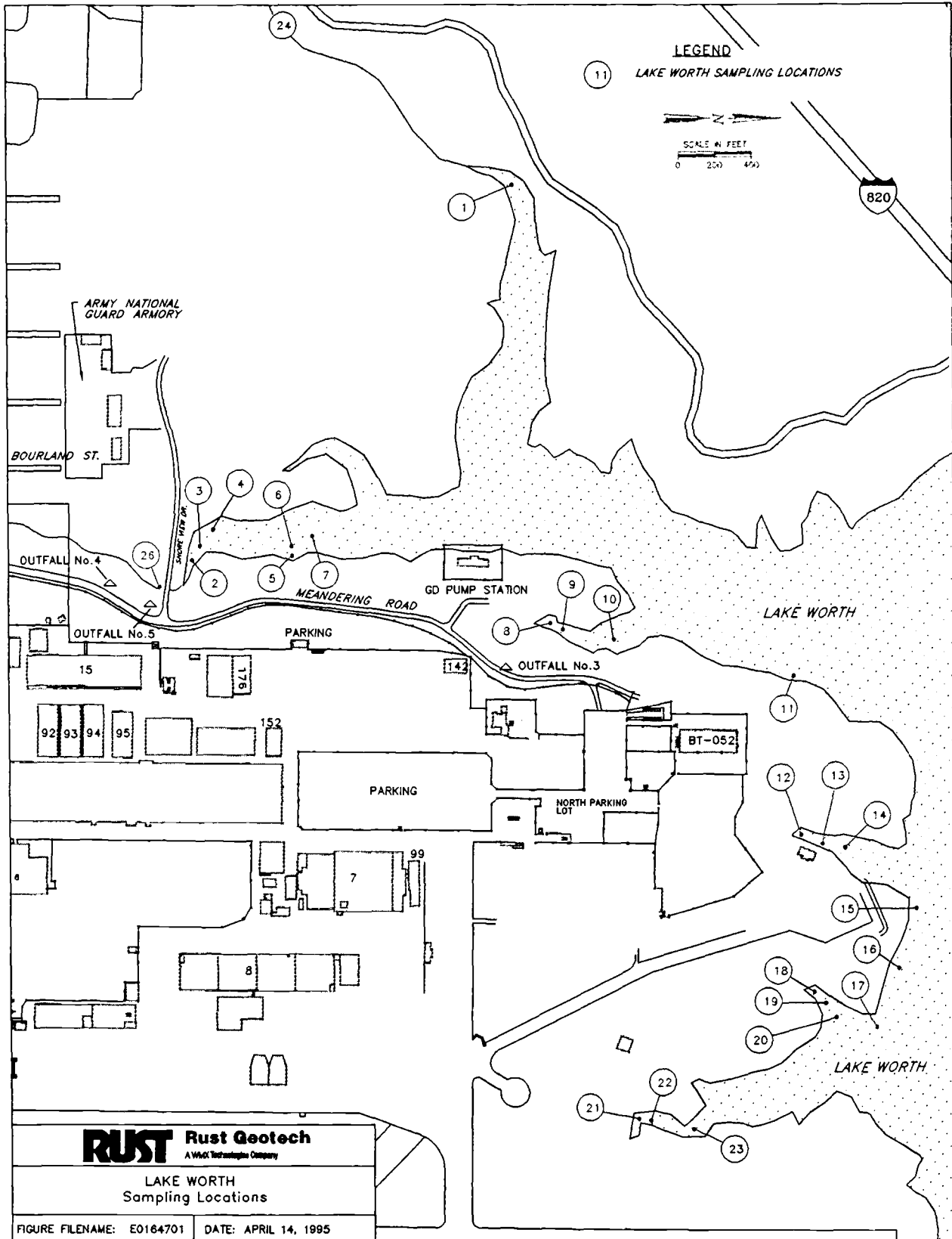


Figure 1-59. Lake Worth Sampling Locations.

Table 1-66. Summary of Lake Worth Sediment Samples

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LOCATION		TYPE OF ANALYSIS										
1	BKG	VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs	PCBs/Pesticide	RAD	Grain	Moisture	TOC
2		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs	PCBs/Pesticide		Grain	Moisture	TOC
3												
4							PAHs			Grain	Moisture	TOC
5		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs			Grain	Moisture	TOC
6							PAHs			Grain	Moisture	TOC
7							PAHs			Grain	Moisture	TOC
8		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs			Grain	Moisture	TOC
9							PAHs			Grain	Moisture	TOC
10							PAHs			Grain	Moisture	TOC
11		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs			Grain	Moisture	TOC
12		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs		RAD	Grain	Moisture	TOC
13							PAHs			Grain	Moisture	TOC
14							PAHs			Grain	Moisture	TOC
15									RAD			
16									RAD			
17									RAD			
18		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs			Grain	Moisture	TOC
19							PAHs			Grain	Moisture	TOC
20							PAHs			Grain	Moisture	TOC
21		VOCs	Semi-VOCs	Metals (1)	TPH	O&G	PAHs			Grain	Moisture	TOC
22							PAHs			Grain	Moisture	TOC
23							PAHs			Grain	Moisture	TOC
24							PAHs	PCBs/Pesticide		Grain	Moisture	TOC
25 Tissue sampling only, also sampled as SW-5												
26							PAHs			Grain	Moisture	TOC
27 Biotoxicity Sampling												
28 Tissue sampling only												
Notes:		Metals analysis for aluminum, cadmium, chromium, lead, and nickel.										
Metals (2)		Priority-Pollutant Metals as in Sampling Plan										
Metals (1)		Oil and Grease										
O&G		Polynuclear Aromatic Hydrocarbons										
PAHs		Radioisotope Analysis										
RAD		Semivolatile Organic Compounds										
Semi-VOCs		Total Petroleum Hydrocarbons										
TPH		Volatile Organic Compounds										
Vocs		Grain Size Analysis										
Grain		Total Organic Content										
TOC		% Moisture										
Moisture												

Notes:

- Metals (2) - Metals analysis for aluminum, cadmium, chromium, lead, and nickel.
- Metals (1) - Priority-Pollutant Metals as in Sampling Plan
- O&G - Oil and Grease
- PAHs - Polynuclear Aromatic Hydrocarbons
- RAD - Radioisotope Analysis
- Semi-VOCs - Semivolatile Organic Compounds
- TPH - Total Petroleum Hydrocarbons
- Vocs - Volatile Organic Compounds
- Grain - Grain Size Analysis
- TOC - Total Organic Content
- Moisture - % Moisture

Sampling Results

Results of Lake Worth Background Location Sediment Sampling: The location of the background sampling site was chosen with the agreement of EPA personnel. The site was to be close enough to Plant 4 to be considered a similar habitat but far enough away to be unaffected by potential contamination from Plant 4 or other industrial sites. However, contaminants were detected at the background location (Location No. 1, see Figure 1-59), with both organic and inorganic contaminants detected. TCE, TPH, and oil and grease at the background location were found only in the deeper sample with results of 160 $\mu\text{g/kg}$, 169 mg/kg, and 290 mg/kg, respectively (see Table 1-67).

Acetone and 2-butanone were found in both depth intervals at relatively the same concentration (see Table 1-68). Inorganic results at the background location were elevated for chromium, lead, and zinc, with levels for sample intervals 0- to 11-inches/11- to 22-inches of 23.6/16.2 mg/kg (Cr), 84.1/164 mg/kg (Pb), and 74.3/43.5 mg/kg (Zn). Sampling Location 24 was located several hundred yards up drainage from the lake background site and was sampled for PAH and PCB/pesticides. Fourteen PAH compounds were detected at levels ranging from 10 $\mu\text{g/kg}$ to 130 $\mu\text{g/kg}$. The drainage leading to the background location was also examined for possible sources of contaminants, with nothing unusual observed that may have caused or contributed to contamination levels. This area does receive flow from a permanent creek that drains a large area.

Results of Lake Worth Sediment Sampling for Organic Compounds: Contaminants above the CRQL were detected in the sediments of Lake Worth at 7 of the 8 locations that were sampled for VOCs (see Tables 1-68 and 1-69). Eight of the 23 lake sampling locations were sampled for VOCs, TPH, and oil and grease (see Table 1-67). TPH was detected at 5 locations, and oil and grease were detected at 6 locations. Samples were collected for semivolatile analysis at 8 locations and PAH analysis at 21 locations. The PAH analysis also indicates semivolatile compounds that were detected at all 21 locations (see Table 1-70). Three sediment samples were analyzed for PCB/pesticides, with two results slightly over the detection limit (see Table 1-71) for the PCBs Aroclor-1260 and -1254. Aroclor-1260 was detected at both Location 1 (background location) and Location 2 (mouth of creek). Aroclor-1254 was detected only at Location 2.

Results of Lake Worth Sediment Sampling for Inorganic Compounds: Sample results from the lake coves and from 3 locations just off-shore indicate high levels of Al, Cu, Pb, and Zn at several of the lake sediment sampling locations (see Table 1-72). Locations with the highest results were in the cove of the lake where Meandering Road Creek flows into Lake Worth. The background location also had elevated results for metals. These were the only sampling locations with permanent creeks flowing into the lake. Other lake sampling locations receive storm runoff only. Table 1-73 presents significant results by location.

Two types of metals analysis were run on selected samples. Aluminum, cadmium, chromium, nickel, and lead were selected for analysis using procedures specified by the USFWS to aid in their evaluation of the inorganic data. Analysis was to be by the more stringent of either FWS-9-OAS-91-111 USFWS or the EPA Method 7000 Series. The selected metals were analyzed by a USFWS contract laboratory using the EPA Method 7000 Series. These metals are used in aircraft production, are constituents in fuels, or were identified as chemicals of concern in the risk assessment. This group of selected metals was analyzed in addition to the Priority-Pollutant Metals (PPMTL). Sampling location LWS 3-01 was sampled for both PPMTL and selected metals with cadmium, chromium, and lead analyzed in both tests. The select metals analysis results for chromium and lead

Table 1-67. Location Summary of VOC, Oil and Grease, and TPH Sediment Samples Collected from Lake Worth

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Location	VOCs	0 to 11 inches (µg/kg)	11 to 22 inches (µg/kg)	Oil and Grease (mg/kg)	TPH (mg/kg)
1 BKG Site	acetone 2-butanone TCE	230 53 ND	190 46 160	NS/NA / 290	NS/NA / 169
2	acetone carbon disulfide 2-butanone TCE	57 ND 16 44	NS 24 ND ND	476/740	323/616
3	sampled for inorganics				
4	sampled for inorganics / PAH				
5	acetone	41	44	602/893	412/623
6	sampled for inorganics / PAH				
7	sampled for inorganics / PAH				
8	acetone	33	NS	266/NS	199/NS
9	sampled for inorganics / PAH				
10	sampled for inorganics / PAH				
11	acetone 2-butanone	85 22	ND 35	ND/ND	ND/ND
12	acetone	15	28	96/13	61/ND
13	sampled for inorganics / PAH				
14	sampled for inorganics / PAH				
15	radioisotope only				
16	radioisotope only				
17	radioisotope only				
18	acetone	ND	43	15/80	
19	sampled for inorganics / PAH				
20	sampled for inorganics / PAH				
21	acetone 2-butanone	47 18	47 23	ND/ND	ND/ND
22	sampled for inorganics / PAH				
23	sampled for inorganics / PAH				
24	sampled for PAH, PCB/pesticide				
25	no sediment sampling				
26	sampled for inorganics / PAH				

ND = Not detected; NS = Not sampled; NA = Not analyzed.

**Table 1-68 Summary of Lake Worth VOC, TPH,
and Oil and Grease Sediment Sampling Analytical Results**

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. above CRQL
Acetone	(11)	230	16	12
Carbon Disulfide	(6)	24	16	1
2-Butanone	(11)	53	16	7
Trichloroethene	(6)	160	16	2
Oil and Grease	(10) mg/kg	893 mg/kg	15	11
Total Petroleum Hydrocarbons	(10) mg/kg	623 mg/kg	15	10

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Trichloroethene was identified by the Baseline Risk Assessment as a chemical of concern.

**Table 1-69 Summary of Lake Worth Semivolatile Sediment
Sampling Analytical Results**

Analyte	Minimum µg/kg	Maximum µg/kg	Number of Samples Analyzed	Number above CRQL
Anthracene	(860)	1,500	19	1
Benzo(a)anthracene	(900)	7,900	19	4
Benzo(a)pyrene	(900)	4,900	19	4
Benzo(b)fluoranthene	(900)	6,200	19	4
Benzo(g,h,i)perylene	(860)	5,100	19	4
Benzo(k)fluoranthene	(900)	4,700	19	4
Bis(2-Ethylhexyl) phthalate	920	2,400	19	3
Chrysene	(860)	6,200	19	4
Dibenz(a,h)anthracene	(900)	1,300	19	1
Fluoranthene	960	7,300	19	7
Indeno(1,2,3-cd)pyrene	(860)	4,200	19	3
Phenanthrene	(900)	4,500	19	5
Pyrene	1100	7,000	19	6

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, and benzo(a)pyrene have been identified in the Risk Assessment as a chemical of concern.

**Table 1-70 Summary of Lake Worth Sediment Samples Collected
for Polynuclear Aromatic Hydrocarbon Analysis**

Analyte	Minimum mg/kg	Maximum mg/kg	No. of Samples Analyzed	No. above CRQL
1,2-Benzanthracene	(0.01)	1.7	23	16
1,2,5,6-Dibenzanthracene	(0.01)	0.45	23	16
Anthracene	0.01	0.57	23	15
Benzo(a)pyrene	0.01	1.3	23	18
Benzo(b)fluoranthene	0.02	1.9	23	18
Benzo(e)pyrene	0.01	1.6	23	17
Benzo(g,h,i)perylene	0.01	1.8	23	18
Benzo(k)fluoranthene	0.01	0.91	23	17
Chrysene	0.01	2.3	23	17
Fluoranthene	(0.01)	5.6	23	17
Fluorene	0.01	0.39	23	13
Naphthalene	(0.01)	0.12	23	16
Phenanthrene	(0.01)	4.4	23	15
Pyrene	(0.01)	4.5	23	17

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene, fluoranthene, naphthalene, and benzo(e)pyrene have been identified in the Risk Assessment as chemicals of concern.

**Table 1-71 Summary of Lake Worth Sediment Samples Collected
for PCB/Pesticide Analysis**

Analyte	Minimum mg/kg	Maximum mg/kg	No. of Samples Analyzed	No. above CRQL
Aroclor-1260	(0.05)	0.11	3	2
Aroclor-1254	(0.05)	0.1	3	1

- Notes: 1) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 2) Concentration in parentheses indicates the compound was not detected at the reported value.

were 35 and 56 mg/kg, respectively. The PPMTL results were 124 and 444 mg/kg. These samples were collected on two different days at approximately the same location. Lake sampling locations were established by lining up with landmarks on shore. Samples with a higher proportion of silts and sands (see Table 1-74) usually had elevated analytical results over samples with a high proportion of clay.

Table 1-72. Summary of Lake Worth Inorganic Sediment Sampling Results

Analyte	Minimum Lake Worth Sediment mg/kg	Maximum Lake Worth Sediment mg/kg	Range in Background Soils ³ (mg/kg)	No. of Samples Analyzed	No. Above Natural Background for the Western USA ³
Aluminum	2750	11750	14,500 - 232,000	14	0
Arsenic	3.5	6	1.4 - 21.6	18	0
Cadmium	0.4	11.4	NA - 2.8 ⁴	32	11
Chromium	4.7	124	8.5 - 196.6	32	0
Copper	8.5	88.4	4.9 - 90.0	18	0
Lead	8	444	5.2 - 55.1	32	12
Nickel	(6)	18.1	3.4 - 66.2	32	0
Silver	(1.1)	13	NA - 1.4 ⁵	18	2
Zinc	21.9	303	17.2 - 176.2	18	3

- Notes:
- 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 - 2) Cadmium, chromium, copper, nickel, and zinc have been identified in the risk assessment as chemicals of concern.
 - 3) From range in Background Soils of Western USA, Shacklette and Boerngen (1984).
 - 4) Upper Background range for cadmium is estimated at 2.8 which is based on twice the observed mean for the four Plant 4 background samples.
 - 5) Upper Background range for silver is estimated at 1.4 which is based on twice the IDL observed mean for the four Plant 4 background samples.

Results of Lake Worth Sediment Sampling for Radioisotopes: Samples collected from drainages near the former NARF area were scanned in the field for alpha, beta, and gamma radiation to determine if special personnel protection or shipping methods were required. No levels over background were detected. All radioisotope sediment samples were dried and analyzed for cobalt-60, cesium-137, radium-226, thorium-230, and uranium. Table 1-75 lists the results of the analysis by sample location. All results are indicative of background levels of radiation in soil. Uranium analysis was by EPA method 6010 with results reported in mg/kg. Background values for uranium in soil are based on a range of 0.86 - 7.25 mg/kg (mean \pm 2 standard deviations) for the western United States, (Shacklette and Boerngen 1984) with a mean value of 2.5 mg/kg. The mean value for Plant 4 uranium analysis was 1.19 mg/kg. The cobalt-60, cesium-137, and radium-226 analysis were by gamma spectroscopy and the thorium-230 analysis was by alpha spectrometry. All results except uranium were reported in units of picoCuries per gram (pCi/g). Cobalt-60 was not included in Table 1-75 as it was not detected in any sample. All analytical results for radiologic samples were within two standard deviations of the samples collected from the background location.

Conclusions

Sample results indicate some contamination of Lake Worth sediments is present in near-shore sediments at Plant 4. The VOC contaminants include acetone and 2-butanone (common laboratory contaminants) TCE, and carbon disulfide. TPH and oil and grease were also detected in the lake sediment samples and are also commonly detected at Plant 4. The organic chemicals of concern benzo(a)pyrene, fluoranthene, pyrene, and TCE were identified in lake sediment samples.

**Table 1-73 Location and Analytical Results of Inorganic Sediment
Samples Collected from Lake Worth**

Sample ID	Cadmium	Chromium	Copper	Lead	Zinc	Aluminum	Nickel
Background Western United States	NA	8.5-196.6	4.9-90	5.2-55.1	17.2-176.2	14,500-232,000	3.4-66.2
LWS 1-01	2.3	23.6	19.2	84.1	74.3		
LWS 1-02		16.2	12.4	164	43.5		
LWS 2-01	5.5	81.7	88.4	153	209		
LWS 2-02	7.3	73	58.1	49.1	249		
LWS 3-01	3.45	35		56		6,400	14.8
LWS 3-01	11.4	124	68.6	444	303		
LWS 3-02	4.4	44.5	40.5	228	157		
LWS 4-01	5.6	40		35.5		7,600	16.8
LWS 5-01	2.8	12.7	13.6	104	69		
LWS 5-02	2.2	29.2	18.6	113	90.4		
LWS 6-01	0.6	9.5		20.5		2,750	9.4
LWS 7-01	4.25	56.5		125		8,600	18.1
LWS 8-01	2.3	25.3	12.3	15.2	33.9		
LWS 9-01	2.75	20		90		4,150	11.3
LWS 10-01	0.5	8.95		19.5		9,450	14.3
LWS 11-01	3.5	23.3	12.8	17.8	56.2		
LWS 11-02	4.6	22.2	15.9	27.9	44.9		
LWS 12-01	1.6	17.9	6.4B	10.1	40.8		
LWS 12-02	ND	12.2	5.3B	158	24		
LWS 13-01	0.55	12.15		22		9,450	11.6
LWS 13-02	0.5	7.5		23		5,750	9.3
LWS 14-01	0.75	12.25		25.5		11,750	12.4
LWS 18-01	1.9	14.7	20.5	34.3	48.7		
LWS 18-02	ND	13.5	13.6	21.3	41.9		
LWS 18-03	1.6	9.1	11.8	16.2	34.9		
LWS 19-01	0.9	10.75		27.5		6,000	10.5
LWS 20-01	0.65	4.7		16.6		4,750	8.3
LWS 21-01		8.3	7.4B	12.3	27.6		
LWS 21-02		10.3	8.5	8	21.9		
LWS 22-01	1.0	70		43		4,900	8.1
LWS 23-01	0.4	6.85		16.1		4,450	14
LWS 23-01D	3.35	35		56.5		6,450	14.7

- Notes:
- 1) Concentrations are reported in mg/kg.
 - 2) Cd, Cr, Cu, Ni, and Zn have been identified in the Baseline Risk Assessment as chemicals of concern.
 - 3) ND = Not detected. Blank means not sampled.
 - 4) Minimum and Maximum are based on all values above the CRQL and those qualified U and B.
 - 5) Al, Cd, Cr, Ni, and Pb were analyzed as selected metals. These metals were selected in agreement with US Fish and Wildlife and EPA Region VI personnel because they are used in aircraft manufacturing, are constituents in fuels, or were identified as chemicals of concern in the risk assessment.

Table 1-74. Summary of Lake Worth Ecological Sediment Samples

Sample ID	TOC (%)	Moisture (%)	Grain Size Analysis		
			Clay (%)	Silt (%)	Sand (%)
LWS1-01	2.0	54.0	31.1	55.5	13.4
LWS2-01	1.8	28.2	17.4	31.0	51.6
LWS2-02	2.1	29.6	23.2	40.5	36.2
LWS4-01	3.0	39.0	21.5	38.3	40.2
LWS5-01	2.3	39.6	16.5	33.9	49.6
LWS6-01	1.0	42.6	20.8	32.2	47.0
LWS7-01		53.0			
LWS8-01	1.9	35.2	13.2	24.8	62.0
LWS9-01	0.4	28.0	8.0	21.4	70.6
LWS10-01	1.0	29.6	13.5	31.5	55.0
LWS11-01	0.9	42.2	45.5	17.7	36.8
LWS12-01	0.6	30.0	21.6	43.2	35.2
LWS13-01	0.6	39.0	15.7	18.3	66.0
LWS13-02		30.8			
LWS14-01	0.9	49.4	16.4	19.8	63.8
LWS18-01	1.9	38.8	21.0	38.1	40.9
LWS19-01	2.2	37.6	29.8	45.0	25.2
LWS20-01		54.2			
LWS21-01	2.4	30.2	21.3	40.3	38.3
LWS22-01	1.1	41.0	12.7	22.0	65.2
LWS23-01	1.7	28.8	18.5	25.7	55.9
LWS24-01		33.0			
LWS26-01	1.1	28.4	14.2	22.7	63.3

a — Numerical average of multiple values.

Semivolatile compounds detected in the lake are frequently related to asphalt and could be a result of storm runoff. The inorganic chemicals of concern, chromium, copper, and zinc were all detected at levels above the site average. Levels of some metals are high when compared to other reported values for Plant 4 soil samples. Concentrations of metals in the sediments did not appear to follow a pattern; samples collected close to shore at the six coves were not consistently higher than samples collected further out in the lake. Samples collected for radiation level analysis from areas adjacent to the former NARF site did not indicate any levels of radiation above background. Samples collected at the background location had some of the highest VOC and metals levels of all sediment samples collected from the lake and may indicate a source of contamination not associated with Plant 4. The background location was selected in agreement with EPA Region VI and Geotech representatives, and was chosen to be as close as possible to Plant 4 to be of similar habitat, but far enough away to be unaffected by potential contamination from Plant 4 or other industrial sites.

Table 1-75. Summary of Lake Worth Radioisotope Sediment Sampling Results

Sample ID	Cesium-137 pCi/g	Radium-226 pCi/g	Thorium-230 pCi/g	Uranium mg/kg
LWS 1-01	.53	1.19	1.1	1.4
LWS 12-01	ND	.86	1.5	.81B
LWS 15-01	ND	.7	2	2.7
LWS 16-01	ND	.45	.8	.58B
LWS 17-01	0.1	.47	.6	.37B
LWS 18-01	ND	.94	1.2	1.3
LWS 18-02	ND	.82	1.2	1.1

Note: 1) "B" indicates value is below CRDL but is greater than or equal to the IDL.
 2) Cobalt-60 analysis for all samples were less than 0.04 pCi/g.
 3) ND = Not detected.

1.5.4.2 Meandering Road Creek Sediment Sampling

Introduction

Upper-zone groundwater is known to discharge from Plant 4 through seeps located along the Meandering Road Creek drainage. Much of the upper-zone groundwater upgradient of the seeps is known to be contaminated with fuels, solvents, oil and grease, and metals. A potential exists for contamination of surface waters and sediments as a result of this discharge. It is also suspected that the creek is providing recharge to the Paluxy Aquifer. A potential exists for contaminant migration into the Paluxy Aquifer, which is used for domestic water supplies in surrounding communities.

The objective of the Meandering Road Creek study was to determine the extent of creek sediment and surface-water contamination originating from Plant 4. Samples along the creek channel were needed to better define the locations of contamination entering Meandering Road Creek from Plant 4. Surface water and sediment samples were collected upstream of Landfill No. 4 to determine potential contamination to the surface-water pathway from sources located upstream from where the creek enters the Plant 4 facility boundary. Several seeps were identified and sampled in addition to those previously sampled to assist in the upper zone characterization.

New sampling locations were established both upstream of Landfill No. 4 and between previously established sampling locations (C-X) to better define the distribution of contaminants (see Figure 1-60).

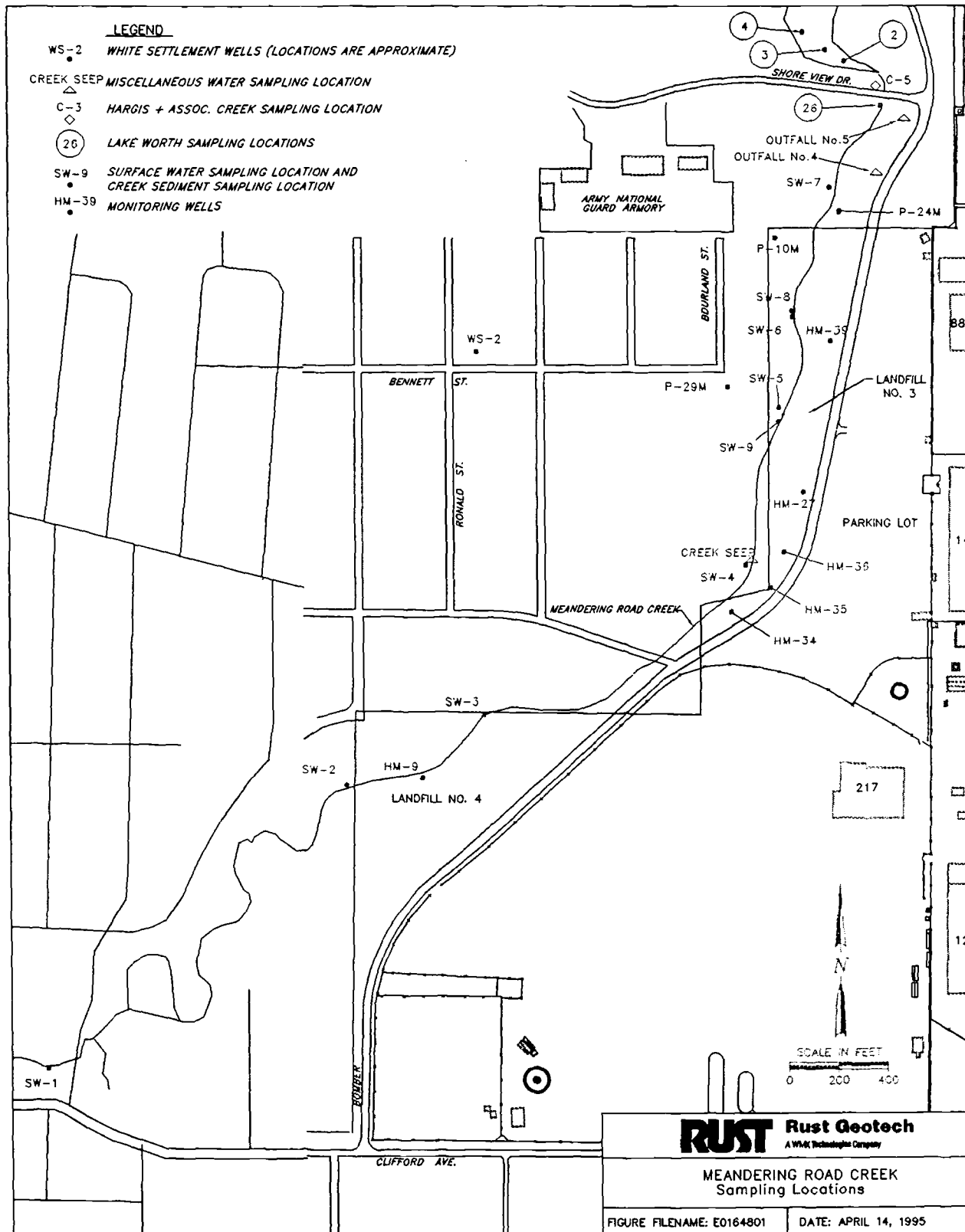


Figure 1-60. Meandering Road Creek Sampling Locations.

Sediment Sampling

Sediment samples were collected from seven locations along Meandering Road Creek (SW-1 to SW-7) (see Figure 1-60) and analyzed for VOCs, semi-VOCs, metals, TPH, and oil and grease. No sediment samples were collected from seep locations SW-08 and SW-09. Locations SW-10 and SW-11 are west of Meandering Road next to Outfall No. 3 (near FSA-3) and water samples were collected for analysis to determine if seeps from the FSA-3 area were contaminated.

Soil samples were collected from sampling locations SW-01 through SW-07 along Meandering Road Creek. Results above the CRQL were reported for VOCs and TPH at several locations (see Table 1-76). Oil and grease (209 mg/kg), TPH (110 mg/kg), and toluene (290 µg/kg), were found in the sediment at SW-01, which is south and upgradient of Landfill No. 4. At location SW-2, also upgradient of Landfill No. 4, the concentrations of oil and grease and TPH were approximately half that of location SW-01.

Table 1-76. Summary of VOC, TPH and Oil and Grease Results for Meandering Road Creek SW-01 through SW-07 Sediment Samples

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
2-Butanone	(11)	17	10	1
Acetone	(11)	58	10	8
cis-1,2-Dichloroethene	(5)	150	10	2
Toluene	(5)	290	10	1
Vinyl Chloride	(11)	20	10	1
Oil and Grease	12	209	7	7
Total Petroleum Hydrocarbons	(10)	110	7	5

- Notes:
- 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 - 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 - 3) Toluene was identified in the Baseline Risk Assessment as a chemical of concern.

SW-2 semivolatile results indicated 4-methylphenol (380J µg/kg), which is commonly used as a disinfectant or fumigant along with several asphalt or coal tar semivolatiles such as fluoranthene and pyrene at 100 µg/kg each. No semivolatiles were detected at SW-3, just downstream from Landfill No. 4. In the area above Landfill No. 4, the creek receives runoff from several streets and parking lots, which may contribute to fuel or asphalt related contaminants (See Table 1-77).

**Table 1-77. Summary of Semivolatile Results for Meandering Road Creek
SW-01 through SW-07 Sediment Samples**

Analyte	Minimum μg/kg	Maximum μg/kg	No. of Samples Analyzed	No. Above CRQL
Fluoranthene	(830)	1,400	9	2
Pyrene	(830)	1,200	9	1

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
 3) Pyrene and fluoranthene were identified in the Risk Assessment as chemicals of concern.

Samples taken adjacent to Landfill No. 3 and further downstream indicate increasing levels of VOCs. Sample results from SW-04 at the south end of Landfill No. 3 show small amounts of semi-VOCs, no VOCs, and TPH at 73 mg/kg. At location SW-05 only VOCs in soil were analyzed, indicating *cis*-1,2-DCE at 150 μg/kg, vinyl chloride at 20 μg/kg, and acetone at 24 μg/kg. Location SW-06 soil samples indicated *cis*-1,2-DCE at 15 μg/kg, acetone at 20 μg/kg, elevated levels of 2 semi-VOCs, (see Table 1-77), oil and grease at 58 mg/kg, and TPH at 14 mg/kg. Location SW-07, north of Landfill No. 3, had low levels of contaminants, with acetone at 38 μg/kg being the only VOC reported. Results above the CRDL for inorganics were reported at several locations (see Table 1-78). Inorganics with values higher than the natural background (from Range in Soils of Western USA, Shacklette and Boerngen 1984) were reported at three locations. Silver was reported at SW-02 (2.9B mg/kg) and SW-06 (6.9 mg/kg). At SW-07, lead levels higher than the background range were detected with values of 77.4 mg/kg.

Transect Sampling Site

Seven soil samples were collected from the surface to a depth of 2 feet at six locations on the west side of Landfill No. 3, near monitoring well F-214, to determine how contamination was distributed in the creek channel area. The five transect sampling locations were on an east-west line, approximately 30-feet long, that originated at CS-002, adjacent to the SW-5 creek sampling location, and extended to CS-005, which was about 10 feet below the surface of Landfill No. 3 (Figure 1-61). Transect samples were collected from a gully in the edge of the landfill that was approximately 5-feet deep. An attempt was made to collect samples on an even spacing, but the amount of concrete rubble on the edge of the landfill made this difficult. Soil samples were analyzed for VOCs, semi-VOCs, metals, and oil and grease. CS-001 was collected approximately 60-feet south of the transect site near suspected seep SW-09. CS-004 was collected as a duplicate of CS-003.

VOC results above the CRQL were reported for three compounds at this site (Table 1-79). VOC results for CS-001 indicated 63 μg/kg of chlorobenzene and an estimated value for 1,2-DCE at 290J μg/kg. CS-002 had 1,2-DCE reported at 180 μg/kg. CS-003, -004, -005, -006, and -007 had

**Table 1-78. Summary of Inorganic Analytical Results for Meandering Road Creek
SW-01 through SW-07 Sediment Samples**

Analyte	Minimum mg/kg	Maximum mg/kg	Range in Background soils ³ mg/kg	No. of Samples Analyzed	No. Above Natural Background ⁵
Antimony	(11.2)	(16.3)	0.1 - 2.2	7	0
Arsenic	3.1	6.1	1.4 - 21.6	7	0
Cadmium	(1.1)	2.4	NA - 2.8 ⁴	7	0
Chromium	8.9	72.7	8.5 - 196.6	7	0
Copper	15.9	17.8	4.9 - 90.0	7	0
Lead	10	77.4	5.2 - 55.1	7	1
Nickel	(7)	(10.2)	3.4 - 66.2	7	0
Selenium	(.56)	(.82)	0 .04 - 1.4	7	0
Silver	(1.1)	6.9	NA- 1.4 ⁵	7	2
Thallium	(.56)	(.82)	(50) - 0.8 ⁶	7	0
Zinc	17.8	87	17.2 - 176.2	7	0

- Notes:
- 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 - 2) Cadmium, chromium, copper, nickel, and zinc were identified in the Baseline Risk Assessment as chemicals of concern.
 - 3) Range in Background Soils of the Western USA, (Shacklette and Boerngen 1984).
 - 4) Upper Background range for cadmium is estimated at 2.8 which is based on twice the observed mean for the four Plant 4 background samples.
 - 5) Upper Background range for silver is estimated at 1.4 which is based on twice the IDL observed mean for the four Plant 4 background samples.
 - 6) Upper Background range for thallium is estimated at 0.8 which is based on twice the IDL observed for the four Plant 4 background samples.

negligible levels of VOCs. Oil and grease results for the seven samples were as follows: CS-001 and -002, not detected; CS-003 and -004, 56, and 63 mg/kg, respectively; and CS-005, -006, and -007, were 956, 632, and 638 mg/kg, respectively. Soil samples from the transect sampling were taken within 25 feet of the SW-05 site with the CS-002 sediment samples collected within 10 feet of the creek at the SW-05 site. CS-002 VOC results indicated 1,2-DCE at 180 $\mu\text{g/kg}$, and vinyl chloride at 6 $\mu\text{g/kg}$ (with a "J" QA qualifier indicating an estimated quantity). Semi-VOC results above the CRQL were reported at several locations (see Table 1-80). The semi-VOCs reported are those commonly found in asphalt, such as pyrene and fluoranthene. Asphalt pavement fragments and particles were observed during sampling in this area.

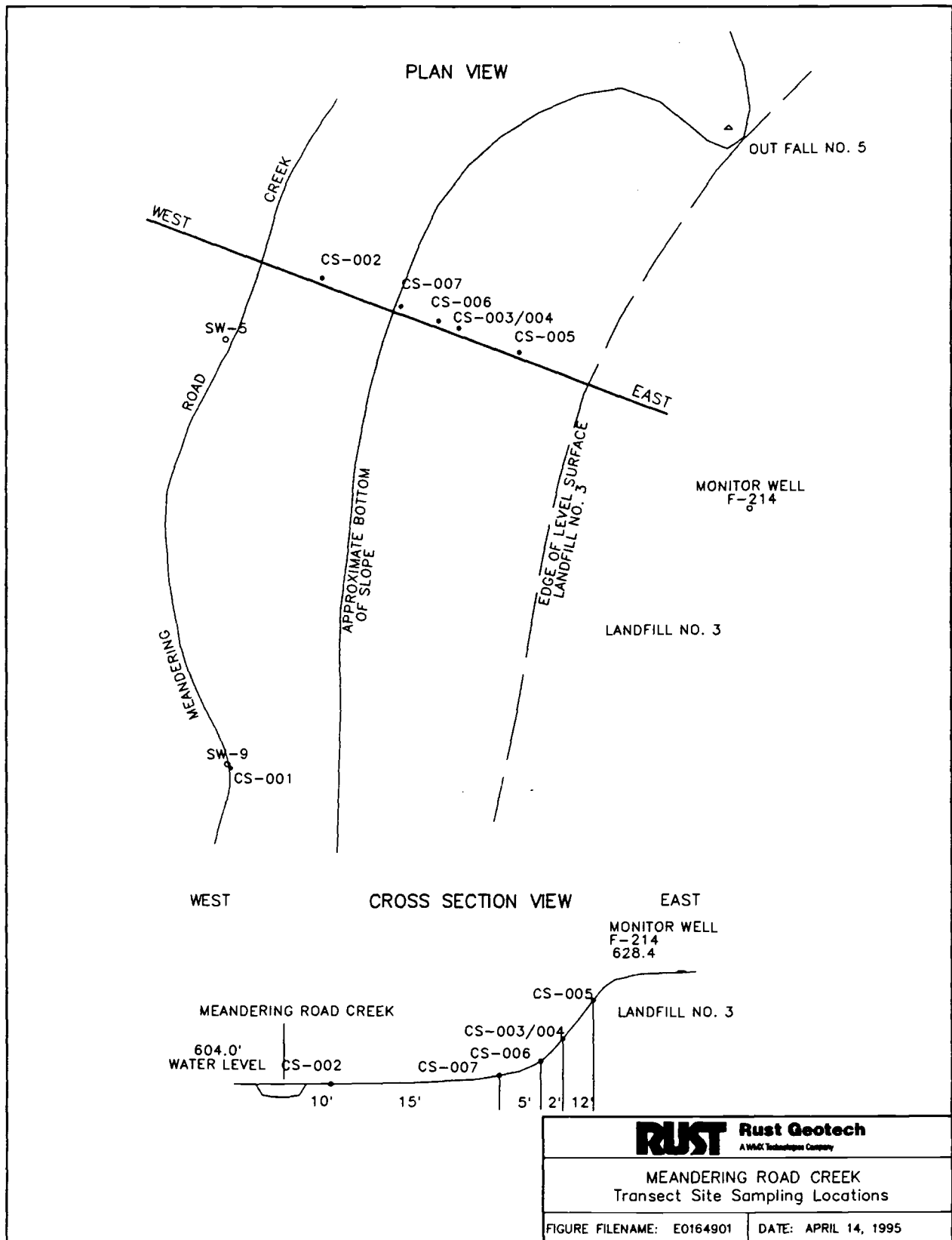


Figure 1-61. Meandering Road Creek Transect Site Sampling Locations.

Table 1-79. Summary of VOC and Oil and Grease Analytical Results for Soil Samples CS-01 through CS-07 Collected at the Transect Site Adjacent to Meandering Road Creek

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
1,2-Dichloroethene	(6)	180	7	1
Acetone	(11)	40	7	1
Chlorobenzene	(6)	63	7	1
Oil and Grease	(10)	956	7	5

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.

Table 1-80. Summary of Semi-VOC Analytical Results for Soil Samples CS-01 through CS-07 Collected at the Transect Site Adjacent to Meandering Road Creek

Analyte	Minimum µg/kg	Maximum µg/kg	No. of Samples Analyzed	No. Above CRQL
Anthracene	(780)	1,800	7	2
Benzo(a)anthracene	(780)	6,100	7	2
Benzo(a)pyrene	(780)	5,700	7	2
Benzo(b)fluoranthene	(780)	7,500	7	3
Benzo(g,h,i)perylene	(780)	3,600	7	2
Bis(2-ethylhexyl) phthalate	(960)	1,500	7	1
Chrysene	(780)	4,100	7	2
Fluoranthene	(780)	15,000	7	3
Indeno(1,2,3-cd)pyrene	(780)	4,900	7	2
Phenanthrene	(780)	11,000	7	2
Pyrene	(780)	9,200	7	3

Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
2) Minimum and Maximum are based on all values above the CRQL and those qualified U, D, or E.
3) Pyrene, fluoranthene, and benzo(a)pyrene were identified in the Baseline Risk Assessment, as chemicals of concern.

Several of the samples collected from this site had analytical results for metals that were higher than the range in background soils (Table 1-81). Sample CS-001, collected from sediments at suspected seep SW-09, 60 feet south of the transect site, had metals results that were approximately at background levels. Samples CS-002 through CS-007 had analytical results ranging from 4 to 600 times the background values for metals. The sample collected at CS-007 had results of 17,400 mg/kg for zinc, 10,400 mg/kg for lead, and 369 mg/kg for chromium. Other metals were also reported at elevated levels. CS-005 had results for chromium—347 mg/kg, copper—5,590 mg/kg, nickel—458 mg/kg, lead—5,800 mg/kg, and zinc—2,690 mg/kg. When CS-003 and -004 were collected, bits of asphalt were detected in the soil, which is indicated by the semi-VOC analytical results.

Table 1-81. Summary of Inorganic Analytical Results for Soil Samples CS-01 through CS-07 Collected at the Transect Site Adjacent to Meandering Road Creek

Analyte	Minimum mg/kg	Maximum mg/kg	Range in Background Soils ⁴ mg/kg	No. of Samples Analyzed	No. Above Natural Background ⁴
Antimony	(12.2)	54	0.1 - 2.2	7	1
Arsenic	2.6	21.7	1.4 - 21.6	7	1
Cadmium	1.5	96.2	NA - 2.8	7	4
Chromium	11.6	369	8.5 - 196.6	7	2
Copper	13.4	5,590	4.9 - 90.0	7	4
Lead	10.6	10,400	5.2 - 55.1	7	4
Nickel	11.8	458	3.4 - 66.2	7	2
Selenium	(.45)	(4.7)	0.04 - 1.4	7	0
Silver	(.7)	23.1	NA - 1.4	7	4
Thallium	(.45)	(.55)	(50) - 0.8	7	0
Zinc	22.7	17,400	17.2 - 176.2	7	4

- Notes: 1) Concentration in parentheses indicates the compound was not detected at the reported value.
 2) B qualifier indicates the analyte was detected above the IDL but less than the CRDL.
 3) Cadmium, Chromium, Copper, Nickel, and Zinc are identified in the Baseline Risk Assessment as chemicals of concern.
 4) Range in Background Soils of Western USA, (Shacklette and Boerngen 1984).

Conclusions

Sample results indicate some contamination of Meandering Road Creek sediments may result from sources upstream from Plant 4, such as runoff from parking lots and roads. Volatile organic compounds detected in sediment samples upstream from Landfill No. 3 are fuels related such as toluene (290 µg/kg at SW-01), low levels of oil and grease (209 mg/kg at SW-01 upstream from Landfill No. 4, and dropping to 134 mg/kg just above Landfill No. 3), and low levels (13 to 58 µg/kg) of acetone. Sample data in the area of Landfill No. 3 clearly indicate creek sediment contamination from VOCs, semi-VOCs, and metals. At SW-5 the VOCs in sediments indicate solvent related contaminants such as *cis*-1,2-DCE (150 µg/kg) and vinyl chloride (20 µg/kg). The sample from the SW-6 location, west of the northern section of Landfill No. 3, also detected low levels of *cis*-1,2-DCE (15 µg/kg), along with many asphalt related semivolatiles. These contaminants are commonly detected in soil and water samples from Landfills No. 1 and No. 3, which are the probable source areas for the creek sediment contamination adjacent to Landfill No. 3 and downstream.

The transect samples indicate irregular contamination levels that are typical of a landfill; they represent the material that was dumped at that particular location and may have results different from a sample collected a few feet away. The transect samples were collected from a gully that is actively being eroded by storm runoff, approximately 20 feet from the edge of the creek. This clearly demonstrates soil contaminant transport toward and into the creek.

1.5.5 Groundwater Contamination

This section describes the nature and extent of groundwater contamination at Plant 4. Results of sampling are presented for the two groundwater flow systems potentially impacted by Plant 4 operations, the upper-zone flow system and the Paluxy Formation.

Contaminant transport within the upper-zone groundwater system is controlled in part by the locations of groundwater divides. The locations of these divides correspond closely to the locations of topographic highs in the buried bedrock surface. Hydraulic head data gathered during the RI show that a groundwater divide exists west of the Main Assembly Building/Parts Plant and encroaches into Landfill No. 1 (see Figure II-24 of the RI). The divide trends southwest near Building 12 and southeast across Clifford Avenue. This divide separates groundwater into components flowing east and west. Another divide trending east to west is located at the north end of the Assembly Building. On the local scale, a northerly component of flow exists north of this divide.

The three distinct flow directions within the upper-zone groundwater system have resulted in three separate areas where contamination may exist (see Figure II-12 of the RI). These areas are referred to as (1) East Parking Lot Plume, (2) West Plume, and (3) North Plume. The boundary between the East Parking Lot Plume and the West Plume is a wide zone of flat hydraulic gradient in two areas: the area west of the Assembly Building and between Buildings 14 and 88, and the area west and north of Building 12. Within each plume area, there may exist elevated concentrations of one or more of the following: chlorinated solvents (approaching maximum solubility levels in some areas), degradation products of chlorinated solvents, fuel compounds, fire extinguishing agents, and inorganics.

Groundwater contamination in the Paluxy Aquifer forms two relatively distinct plumes at Plant 4, the West Paluxy Plume and the East Paluxy Plume (Figures II-19a through II-19d of the RI). The West Paluxy Plume occurs within the regional Paluxy Aquifer whereas the East Paluxy Plume occurs largely within the Paluxy Upper Sand beneath the East Parking Lot. It is the lower portion of the regional Paluxy Aquifer that is pumped for water supply by municipal wells south and west of Plant 4.

The top of the regional Paluxy Aquifer is defined as the water table surface within the Paluxy Formation and typically occurs at depth of 10 to 20 feet below the bottom of the Walnut Formation. Contamination in the West Paluxy Plume is suspected to have entered the aquifer either as recharge through the lower reach of Meandering Road Creek, or as vertical migration down the well bore in P-22U and/or P-22M. P-22M was recently abandoned to eliminate the potential for vertical migration along the well bore.

The Paluxy Upper Sand is a local feature in the Paluxy Formation characterized by well-indurated sandstone highly interbedded with shale, siltstone, and claystone. The Upper Sand occurs mainly in the East Parking Lot area, extending west to the west side of the Assembly Building/Parts Plant, east to the flightline area, south to Clifford Avenue, and north past the engineering building. The Paluxy Upper Sand is variably saturated, behaves much like an extension of the Walnut Formation Aquitard, and produces water only in wells completed in the East Parking Lot and flightline areas. As noted above, contamination in the East Paluxy Plume occurs mainly in the Paluxy Upper Sand. This contamination is suspected to have entered the Upper Sand via vertical migration from the Upper

Zone passing through the thin section of Walnut Formation referred to as the window area (Figure 1-8a). Contaminant migration in the Paluxy Upper Sand is discussed in Section 5.3.

The window area is defined as zone where the Walnut Formation has been eroded to a thickness of only 0.5 to 2.5 feet. Beyond the zone referred to as the window area, the thickness of the Walnut Formation generally increases rapidly. Southeast of the window area, the Walnut Formation remains approximately five feet thick out to the vicinity of the flightline area (see lithologic log for P-19US in Appendix K and cross-section 8, Figure II-8 of the RI). Because the dip of the formation contact (37 ft/mile) exceeds the flightline area relief in the erosional surface of the Walnut Formation (5 ft/mile; see Figure II-27 of the RI), the aquitard thickness does increase beyond the flightline as one approaches the CAFB golf course (see lithologic log for CAR-P1 and CAR-P2).

Although all borings through the Walnut Formation have documented aquitard thicknesses of five feet or more outside of the window area, additional areas where the aquitard is thin or absent may yet remain undetected.

Groundwater contamination in the upper zone and the Paluxy Formation is discussed separately for organic and inorganic contamination. Discussions of organic contamination include volatiles and semivolatiles, TPH, and oil and grease.

Groundwater has been monitored at Plant 4 since 1985. The frequency of sampling individual monitoring wells has been monthly, quarterly, semiannually, or annually, depending upon the location of the monitoring well and the sampling objectives. Because of the duration of environmental sampling at Plant 4, various contractors have been involved; consequently, the laboratory analytical methods and data quality objectives have changed over the years. Geotech recognized that information collected by others may be useful for mapping and discussing the extent of contamination at Plant 4. Therefore, the maps and tables which are referenced in the text contain both Geotech data and selected data collected by others.

Groundwater samples collected at Plant 4 by Geotech have been analyzed using EPA Analytical Level III requirements with Level IV reporting for the TCL volatile and semivolatile organic compounds and the TAL metals. Beginning in September 1991 the analyte list for volatile organic compounds was revised to isolate the *cis* and *trans* isomers of 1,2-DCE, and the ortho (*o*-) isomer of xylene. These revisions were made to assess the relative abundance of these isomers, because *trans*-1,2-DCE is approximately twice as toxic as *cis*-1,2-DCE (Verschuere 1983) and *o*-xylene is considered a developmental toxicant (U.S. EPA 1991).

1.5.5.1 Upper-Zone Groundwater: Volatile Organic Contamination

A summary of organic contamination detected within upper-zone groundwater is presented in Table 1-82. TCE is the most common contaminant at the site. Detailed discussions of groundwater contamination within the three contaminant areas are presented in the following sections. NAPLs found floating on or pooled below upper-zone groundwater are summarized in Table 1-83. The locations of monitoring wells containing NAPLs are shown in Figure II-15 of the RI.

**Table 1-82. Summary of VOC Concentrations Reported
Above the CRQL in the Upper-Zone Flow System**

Chemical Name	Minimum Result (µg/L)	Maximum Result (µg/L)	MCL (µg/L)	Number of Samples Analyzed	Number of Samples Exceeding CRQL	Number of Samples Exceeding MCL
<i>o</i> -Xylene	5U	170	—	70	4	—
Trichloroethene	1U	87,000	5	177	134	111
1,1,2-Trichloroethane	1U	660	5	177	2	1
2-Butanone	10	750	—	167	8	—
1,2-Dichloropropane	5U	610	5	167	2	2
1,1-Dichloroethene	1U	2,100	7	177	29	18
1,1-Dichloroethane	1	620	—	177	9	—
Carbon Disulfide	5U	20	—	167	1	—
Methylene Chloride	1U	98,000	5	177	11	9
Vinyl Chloride	2U	6,500	2	177	17	16
1,1,1-Trichloroethane	1U	380	200	177	20	4
Benzene	1U	730	5	177	16	11
Chloroform	1	90	100	177	9	0
Acetone	10U	7,600	—	167	14	—
Carbon Tetrachloride	5U	400	5	167	1	1
1,2-Dichloroethene	5U	69,000	—	97	20	—
<i>trans</i> -1,2-Dichloroethene	1U	22	100	80	11	0
<i>cis</i> -1,2-Dichloroethene	1U	1,500	70	80	42	24
Xylene	1U	12,000	10,000	177	13	2
Tetrachloroethene	1U	450	5	177	4	4
Dibromochloromethane	5U	550	100	167	1	1
Chlorobenzene	1	2,600	100	177	13	4
Toluene	1U	25,000	1,000	177	7	2
1,2-Dichloroethane	5U	30,000	5	167	11	8
Styrene	5U	27	100	167	1	0
Ethylbenzene	5U	5,500	700	167	14	4

Table 1-83. Summary of Non-Aqueous Phase Liquids Detected in Plant 4 Monitoring Wells

Well ID	Site	Type	Thickness (FT)		
			September 1991	March 1991	April 1990
F-202	FSA-3	LNAPL	0.03	NM*	0.26
F-203	FSA-1	LNAPL	0.01	3.53	2.83
F-205	FSA-1	LNAPL	0.36	NM	NM
F-206	FSA-1	LNAPL	0.12	NM	NM
F-210	FSA-3	LNAPL	0.46	NM	0.36
F-222	FSA-3	LNAPL	1.21	NM	NM
FSA3-11	FSA-3	LNAPL	1.01	NM	NM
HM-21	LF-3	LNAPL	0.00	NM	0.01
HM-38	LF-3	LNAPL	0.26	NM	0.01
HM-78	FSA-3	LNAPL	1.14	NM	NM
W-139U	FSA-1	LNAPL	1.01	NM	NM
F-214	LF-3	DNAPL/LNAPL	NM	NM	4.08
W-130	LF-3	DNAPL	NM	1.97 on 4/24/91	NM

NM* = Not Measured

East Parking Lot Plume: Volatile Organics

The largest plume of groundwater contamination is referred to as the East Parking Lot Plume. This plume begins at the groundwater divide located south and west of the Parts Plant and Building 12 (see Figures II-12a, II-12b, II-13a and II-13b of the RI). The plume also has source areas west of the Assembly Building in the vicinity of Buildings 14 and 88. From the main source area south of the Parts Plant, the plume extends in an easterly and northeasterly direction towards the East Parking Lot and later spreads east and southeast in the direction of CAFB. On CAFB, the plume may have merged with CAFB source areas located at CAFB Landfills 4 and 5, Landfill 6 north of Farmers Branch Creek, and the North Apron.

The extent of the East Parking Lot plume is defined by elevated concentrations of TCE, *cis*- and *trans*-1,2-dichloroethene, vinyl chloride, 1,1,2-TCA, 1,1-DCA, 1,1-DCE, methylene chloride, PCE, benzene, toluene, xylene, acetone, chlorobenzene, and chloroform. By far the greatest occurrence of any single organic compound is TCE. The extent of TCE contamination in the upper zone is shown in Figures II-12a, II-12b, II-13a and II-13b of the RI for sampling periods between 1990 and 1995. During the RI, TCE has been detected in concentrations exceeding the CRQL in 50 monitoring wells. A list of wells within the East Parking Lot Plume for which TCE concentrations exceed the CRQL is presented in Table 1-84. All TCE results listed exceed the EPA MCL of 5 µg/L.

**Table 1-84. Upper-Zone Monitoring Wells Within the East Parking Lot Plume
where TCE Concentrations Exceeded the CRQL**

Site ID	Sample ID	Sample Date	Result (µg/L)
F-218	NAA157	27-Apr-90	3,000
F-219	NAA158	26-Apr-90	67
F-219	NAA260	26-Apr-90	71
HM-029	NAA162	27-Apr-90	1,400
HM-031	NAA163	27-Apr-90	920
HM-047	NAA164	27-Apr-90	4,400
HM-047	NAA269	27-Apr-90	7,100
HM-056	NAA168	28-Apr-90	150
HM-060	NAA169	27-Apr-90	170
HM-071	NAA172	28-Apr-90	420
HM-086	NAA173	28-Apr-90	250
HM-087	NAA174	29-Apr-90	350
HM-088	NAA175	01-May-90	6,700
HM-088	NAA271	01-May-90	6,000
HM-089	NAA176	01-May-90	4,500
HM-089	NAA261	01-May-90	4,800
HM-089	NAA272	01-May-90	3,600
HM-094	NAA180	29-Apr-90	19,000
HM-095	NAA181	25-Apr-90	1,900
HM-096	NAA182	25-Apr-90	1,200
HM-097	NAA183	25-Apr-90	440
HM-099	HM-99	25-Oct-91	720
HM-099	NAA185	25-Apr-90	2,100
HM-099	QM-006	14-Mar-91	1,200
HM-099	WQM004	05-Dec-90	2,300
HM-103	NAA186	01-May-90	1,900
HM-110	NAA188	01-May-90	23
HM-111	NAA189	30-Apr-90	410
HM-111	NAA273	30-Apr-90	420
HM-112	NAA190	30-Apr-90	3,700
HM-112	NAA274	30-Apr-90	3,400
HM-113	NAA191	30-Apr-90	380
HM-115	NAA192	01-May-90	110
HM-115	QM-008DL	18-Mar-91	240
HM-115	WQM010	07-Dec-90	320
HM-116	NAA193	01-May-90	860
HM-117	NAA194	01-May-90	640
HM-118	NAA195	01-May-90	180
HM-119	NAA196	01-May-90	25
HM-119	QM-009	18-Mar-91	62
HM-119	WQM007	06-Dec-90	66
HM-121	QM-010DL	19-Mar-91	450
HM-121	WQM009	06-Dec-90	500
HM-122	QM-011DL	19-Mar-91	870

**Table 1-84. (continued) Upper-Zone Monitoring Wells Within the East Parking Lot Plume
Where TCE Concentrations Exceeded the CRQL**

Site ID	Sample ID	Sample Date	Result (µg/L)
HM-122	WQM022	10-Dec-90	890
HM-123	HM-123	25-Oct-91	2,000
HM-123	QM-012	19-Mar-91	120
HM-123	QM-012DL	19-Mar-91	1,900
HM-123	WQM011	07-Dec-90	2,100
HM-125	QM-013	18-Mar-91	66
HM-125	WQM024	10-Dec-90	36
HM-126	NAA203	01-May-90	2,600
HM-127	NAA204	01-May-90	55
LF04-02	LF04-02	27-Oct-91	3,800
LF04-04	LF04-04	27-Oct-91	1,800
LF05-01	LF05-01	28-Oct-91	880
LF05-5A	LF05-5A	27-Oct-91	1,600
W-128L	W-128L-01	12-Sep-91	19
W-128L	W-128L-11	19-Oct-91	19
W-131L	W-131L-01	11-Sep-91	6
W-131U	W-131U-11	24-Oct-91	21
W-131U	W-131U-11EB	24-Oct-91	11
W-131U	W-131U-12	24-Oct-91	20
W-137	W-137-01	16-Sep-91	76
W-137	W-137-11	24-Oct-91	56
W-145	W-145-01	15-Sep-91	8
W-149	W-149-01	18-Sep-91	20,000
W-149	W-149-11	17-Oct-91	21,000
W-150L	W-150-11D	20-Oct-91	4,100
W-150L	W-150L-01DL	14-Sep-91	4,900
W-151	W-151-01DL	13-Sep-91	510
W-151	W-151-11D	21-Oct-91	520
W-153	W-153-01	18-Sep-91	1500
W-153	W-153-02	18-Sep-91	1,300
W-153	W-153-11D	23-Oct-91	1,000
W-153	W-153-12D	23-Oct-91	1,000
W-154	W-154-01DL	14-Sep-91	2,800
W-154	W-154-02DL	14-Sep-91	2,700
W-154	W-154-11D	21-Oct-91	2,500
W-156	W-156-01DL	17-Sep-91	3,900
W-156	W-156-11D	22-Oct-91	3,600
W-158	W-158-01DL	14-Sep-91	15,000
W-158	W-158-11D	20-Oct-91	13,000
W-159	W-159-01DL	14-Sep-91	15,000
W-159	W-159-11D	20-Oct-91	31,000
W-160	W-160-01DL	14-Sep-91	480
W-160	W-160-11D	23-Oct-91	400
WP-07-10A	WP07-10A	27-Oct-91	1,300

The East Parking Lot Plume appears to have several sources of contamination. One major potential source is the degreaser tanks T-534 and T-544 located within Building 181. One documented release from tank T-534 was discovered in June 1991. The volume of this release was estimated to be approximately 20,000 gallons of TCE. The size of the East Parking Lot Plume indicates other releases of organic solvents may have occurred at this location during the past 40 years of operation.

Other potential sources of volatile organic contamination in the East Parking Lot Plume include Chrome Pits Nos. 1, 2, and 3, DYCP, FDTA-2, FDTA-5, and the WWCB. Except for FDTA-2, these potential sources are located along the groundwater divide in the south central portion of Plant 4. Historically, high concentrations (approaching saturation) of TCE have been reported in the south central portion of Plant 4. Groundwater monitoring results from existing wells in the area indicate that contamination may be migrating from the East Parking Lot Plume toward Meandering Road Creek.

Examination of bedrock topography (Figure 1-8b) indicates the presence of a bedrock channel extending from FDTA-2 and running between Buildings 88 and 14. The bedrock channel then extends beneath the Assembly Building/Parts Plant, reemerges in the vicinity of monitoring well HM-56. Since TCE is a DNAPL, it is capable of flowing against the hydraulic gradient, along the base of the bedrock channel in the vicinity of monitoring wells HM-20, HM-29, and F-215. As a dissolved constituent, TCE can be transported by advection beneath the Assembly Building/Parts Plant. East of the Assembly Building, dissolved TCE from FDTA-2 will merge with the main portion of the East Parking Lot Plume.

During the RI, the highest TCE concentrations detected within the East Parking Lot Plume were from monitoring wells located along the axis of the buried East Parking Lot channel, including wells HM-094, W-149, W-158, and W-159. TCE concentrations in these monitoring wells ranged from 15,000 to 31,000 $\mu\text{g/L}$. The fact that concentrations of these magnitudes are found along the axis of the buried channel suggests that TCE may be migrating along the channel in the form of a DNAPL.

Prior to the RI, TCE concentrations exceeding 10,000 $\mu\text{g/L}$ were reported in monitoring wells F-218, F-220, and HM-082. Of particular importance is monitoring well F-220, in which TCE concentrations in excess of 100,000 $\mu\text{g/L}$ were reported. Monitoring well F-220 is located within Chrome Pit No. 3.

The RI results show that the central portion of the East Parking Lot Plume, delineated by the 1,000 $\mu\text{g/L}$ TCE contour, extends approximately 4,000 feet in a northeasterly direction from the potential source area. The southeasterly trending portion of the plume extends southeast over 6,000 feet, onto CAFB (see Figure II-13b of the RI). Assessment of TCE results for wells and sample locations on CAFB confirms the interpreted extent of the TCE plume on CAFB. The distribution of TCE shown in Figures II-12a, II-12b, II-13a, and II-13b of the RI suggests that the sources of contamination are present on both Plant 4 and CAFB property and that these sources have been present for many years.

Monitoring wells located outside the 1,000 $\mu\text{g/L}$ TCE concentration line are typified by low to unquantifiable levels of TCE. Because of the laterally abrupt transition between the upper-zone flow system and the bedrock margin of the buried stream channel, TCE concentrations decrease to below the CRQL over a relatively short distance. The abrupt concentration gradient in the transverse direction is most apparent on Plant 4 property (see Figures II-12 and II-13 of the RI). Where the plume trends southeast across CAFB, the southwest margin of the plume is also distinct due to the presence of the upper-zone flow-system boundary formed by the intersection of the water table and upsloping rock of the Good land Formation. However, the eastern margin of the plume appears rather diffuse, perhaps resulting from an open or more gradual valley margin in that direction.

Since the completion of the RI field work, data collected during a quarterly sampling program (Jacobs Engineering Group, Inc. December 1992) shows increased TCE concentrations for eight Upper-Zone wells in the vicinity of the East Parking Lot and Buildings 181 and 182 (Figure II-12B of the RI). The largest increase occurred at F-218 where the TCE concentration increased from 3,000 $\mu\text{g/L}$ to 180,000 $\mu\text{g/L}$ in October 1992. As shown by Figures II-26 and II-27 of the RI, this well is located along the axis of the buried channel and is downgradient from the degreaser tanks located in Building 181. Other wells showing increased TCE concentrations during post-RI sampling include HM-31 (increased from 920 to 2,400 $\mu\text{g/L}$ in April 1992), HM-110 (23 to 860 $\mu\text{g/L}$ in July 1992), HM-112 (3,700 to 7,200 $\mu\text{g/L}$ in July 1992), HM-103 (1,900 to 3,300 $\mu\text{g/L}$ in October 1992), HM-24 (ND to 5 $\mu\text{g/L}$ in April 1992), W-152 (ND to 2.2 $\mu\text{g/L}$ in October 1992), and HM-104 (ND to 2.0 $\mu\text{g/L}$ in April 1992). With the exceptions of HM-24 and W-152, these increases are likely the result of renewed TCE migration originating with the release that was discovered in June 1991. The small increase at HM-24 may be due to dispersion of TCE originating at Chrome Pit No. 3. The increase at W-152 is likely the result of dispersive transport of TCE originating at FDTA-2.

In the downgradient portion of the East Parking Lot TCE Plume, data collected since the completion of the RI field work shows decreasing TCE concentrations at six wells (Figure II-12B of the RI). These include HM-99 (decreased from 2,300 to 310 $\mu\text{g/L}$ in October 1992), LF05-19 (decreased from 1,300 to 500 and then 45 $\mu\text{g/L}$ in October 1992), HM-116 (decreased from 860 to 560 $\mu\text{g/L}$ in October 1992), HM-119 (decreased from 110 to 94 $\mu\text{g/L}$ in October 1992), HM-121 (decreased from 500 to 470 $\mu\text{g/L}$ in October 1992), and HM-125 (decreased from 94 to 76 $\mu\text{g/L}$ in October 1992).

These near-steady or decreasing levels of TCE near the downgradient boundary suggest that the frontal portions of the East Parking Lot TCE Plume may have reached a maximum distance from the source area. It is possible that in the time required for TCE to migrate from the source areas to the locations of the wells noted above, all or most of the TCE is naturally biodegraded to daughter products such as 1,2-DCE, 1,1-DCE, and vinyl chloride.

Degradation products of TCE are also present within the East Parking Lot Plume. Degradation products include 1,1-DCE, *cis*- and *trans*-1,2-DCE (also reported as total 1,2-DCE), and vinyl chloride (Vogel and McCarty 1985). Table 1-85 lists the wells within the East Parking Lot Plume for which concentrations of TCE degradation products exceed CRQLs. Occurrences of these compounds within the East Parking Lot Plume are presented in Figure II-14 of the RI.

**Table 1-85. Upper-Zone Monitoring Wells Within the East Parking Lot Plume
Where TCE Degradation Product Concentrations Exceeded CRQLs**

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
1,1-Dichloroethene	LF04-02	LF04-02	27-Oct-91	2
1,1-Dichloroethene	LF04-04	LF04-04	27-Oct-91	2
1,1-Dichloroethene	LF05-01	LF05-01	28-Oct-91	2
1,1-Dichloroethene	LF05-5A	LF05-5A	27-Oct-91	3
1,1-Dichloroethene	WP07-10A	WP07-10A	27-Oct-91	2
1,2-Dichloroethene	HM-099	QM-006	14-Mar-91	250
1,2-Dichloroethene	HM-099	WQM004	05-Dec-90	1,100
1,2-Dichloroethene	HM-115	QM-008	18-Mar-91	28
1,2-Dichloroethene	HM-115	WQM010	07-Dec-90	9
1,2-Dichloroethene	HM-121	QM-010	19-Mar-91	13
1,2-Dichloroethene	HM-121	WQM009	06-Dec-90	9
1,2-Dichloroethene	HM-122	QM-011DL	19-Mar-91	3800
1,2-Dichloroethene	HM-122	WQM022	10-Dec-90	290
1,2-Dichloroethene	HM-123	QM-012DL	19-Mar-91	1000
1,2-Dichloroethene	HM-123	WQM011	07-Dec-90	670
cis-1,2-Dichloroethene	HM-099	HM-99	25-Oct-91	440
cis-1,2-Dichloroethene	HM-123	HM-123	25-Oct-91	230
cis-1,2-Dichloroethene	LF04-02	LF04-02	27-Oct-91	390
cis-1,2-Dichloroethene	LF04-04	LF04-04	27-Oct-91	350
cis-1,2-Dichloroethene	LF05-01	LF05-01	28-Oct-91	110
cis-1,2-Dichloroethene	LF05-5A	LF05-5A	27-Oct-91	600
cis-1,2-Dichloroethene	W-131L	W-131L-01	11-Sep-91	7
cis-1,2-Dichloroethene	W-137	W-137-01	16-Sep-91	16
cis-1,2-Dichloroethene	W-137	W-137-11	24-Oct-91	29
cis-1,2-Dichloroethene	W-139L	W-139L-01	16-Sep-91	11
cis-1,2-Dichloroethene	W-139L	W-139L-11	19-Oct-91	9
cis-1,2-Dichloroethene	W-149	W-149-01	18-Sep-91	1,500
cis-1,2-Dichloroethene	W-149	W-149-11	17-Oct-91	1,500
cis-1,2-Dichloroethene	W-150L	W-150-11	20-Oct-91	19
cis-1,2-Dichloroethene	W-150L	W-150L-01	14-Sep-91	34
cis-1,2-Dichloroethene	W-151	W-151-01	13-Sep-91	28
cis-1,2-Dichloroethene	W-151	W-151-01DL	13-Sep-91	25
cis-1,2-Dichloroethene	W-151	W-151-11	21-Oct-91	23
cis-1,2-Dichloroethene	W-151	W-151-11D	21-Oct-91	37
cis-1,2-Dichloroethene	W-153	W-153-01	18-Sep-91	130
cis-1,2-Dichloroethene	W-153	W-153-02	18-Sep-91	120
cis-1,2-Dichloroethene	W-153	W-153-11	23-Oct-91	110
cis-1,2-Dichloroethene	W-153	W-153-11D	23-Oct-91	87
cis-1,2-Dichloroethene	W-153	W-153-12	23-Oct-91	110
cis-1,2-Dichloroethene	W-153	W-153-12D	23-Oct-91	100
cis-1,2-Dichloroethene	W-156	W-156-01	17-Sep-91	170
cis-1,2-Dichloroethene	W-156	W-156-01DL	17-Sep-91	170
cis-1,2-Dichloroethene	W-156	W-156-11	22-Oct-91	170

Table 1-85. (continued) Upper-Zone Monitoring Wells Within the East Parking Lot Plume Where TCE Degradation Product Concentrations Exceeded CRQLs

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
<i>cis</i> -1,2-Dichloroethene	W-158	W-158-01	14-Sep-91	18
<i>cis</i> -1,2-Dichloroethene	W-158	W-158-11	20-Oct-91	19
<i>cis</i> -1,2-Dichloroethene	W-159	W-159-01	14-Sep-91	20
<i>cis</i> -1,2-Dichloroethene	W-159	W-159-11	20-Oct-91	20
<i>cis</i> -1,2-Dichloroethene	W-160	W-160-01	14-Sep-91	170
<i>cis</i> -1,2-Dichloroethene	W-160	W-160-01DL	14-Sep-91	180
<i>cis</i> -1,2-Dichloroethene	W-160	W-160-11	23-Oct-91	120
<i>cis</i> -1,2-Dichloroethene	W-160	W-160-11D	23-Oct-91	110
<i>cis</i> -1,2-Dichloroethene	WP07-10A	WP07-10A	27-Oct-91	440
<i>trans</i> -1,2-Dichloroethene	HM-099	HM-99	25-Oct-91	2
<i>trans</i> -1,2-Dichloroethene	HM-123	HM-123	25-Oct-91	13
<i>trans</i> -1,2-Dichloroethene	LF04-02	LF04-02	27-Oct-91	15
<i>trans</i> -1,2-Dichloroethene	LF04-04	LF04-04	27-Oct-91	11
<i>trans</i> -1,2-Dichloroethene	LF05-01	LF05-01	28-Oct-91	10
<i>trans</i> -1,2-Dichloroethene	LF05-5A	LF05-5A	27-Oct-91	16
<i>trans</i> -1,2-Dichloroethene	W-150L	W-150L-01	14-Sep-91	22
<i>trans</i> -1,2-Dichloroethene	W-160	W-160-01	14-Sep-91	5
<i>trans</i> -1,2-Dichloroethene	WP07-10A	WP07-10A	27-Oct-91	13
Vinyl Chloride	HM-122	QM-011	19-Mar-91	14
Vinyl Chloride	HM-123	HM-123	25-Oct-91	7
Vinyl Chloride	HM-123	QM-012	19-Mar-91	27
Vinyl Chloride	LF04-02	LF04-02	27-Oct-91	3
Vinyl Chloride	LF04-04	LF04-04	27-Oct-91	3
Vinyl Chloride	LF05-01	LF05-01	28-Oct-91	15
Vinyl Chloride	LF05-5A	LF05-5A	27-Oct-91	7
Vinyl Chloride	W-160	W-160-01	14-Sep-91	98
Vinyl Chloride	W-160	W-160-01DL	14-Sep-91	91
Vinyl Chloride	W-160	W-160-11	23-Oct-91	86
Vinyl Chloride	W-160	W-160-11D	23-Oct-91	78
Vinyl Chloride	WP07-10A	WP07-10A	27-Oct-91	4

Analytical results for wells located within the East Parking Lot Plume indicate 1,2-DCE concentrations exceed 1,000 $\mu\text{g/L}$ in monitoring wells HM-099, HM-122, and HM-123, and *cis*-1,2-DCE exceeded 1,000 $\mu\text{g/L}$ in monitoring well W-149 (see Table 1-85 and Figure II-14 of the RI). Analytical results obtained prior to the RI showed that *cis*-1,2-DCE also exceeded 1,000 $\mu\text{g/L}$ in monitoring well HM-089, located within the East Parking Lot. Ten monitoring wells in the East Parking Lot Plume contained *cis*-1,2-DCE in concentrations exceeding 100 $\mu\text{g/L}$, and seven monitoring wells contained *cis*-1,2-DCE in concentrations ranging between the CRQL and 100 $\mu\text{g/L}$ (see Figure II-14 of the RI).

The East Parking Lot Plume also contains low concentrations of 1,1-DCE, *trans*-1,2-DCE and vinyl chloride. RI monitoring results for monitoring wells HM-099, HM-123, LF04-02, LF04-04, LF05-01, LF05-5A, W-150L, W-160, and WP07-10A show that the ratio of *cis*-1,2-DCE to *trans*-1,2-DCE is very high (see Figure II-14 of the RI). In some cases this ratio approaches 20:1, as the *cis*-1,2-DCE isomer exceeds the MCL of 70 $\mu\text{g/L}$. RI monitoring of TCE-degradation products further indicates that vinyl chloride exceeds the MCL of 2 $\mu\text{g/L}$ in monitoring wells HM-122, HM-123, LF04-02, LF05-01, LF05-5A, W-160, and WP07-10A.

During sampling conducted since the completion of the RI fieldwork (Jacobs Engineering Group, Inc. December 1992) *cis*- and *trans*-1,2-DCE were the only TCE degradation products detected in upper-zone groundwater (Figure II-14B of the RI). The *cis*-1,2-DCE isomer was detected in 12 monitoring wells distributed throughout the East Parking Lot Plume. The *trans*- isomer was detected in only one well, HM-31. For the 12 wells containing *cis*-1,2-DCE contamination, six wells showed increased concentrations relative to prior levels, and four wells showed decreased concentrations relative to prior levels. Two of the 12 wells had not been sampled during the RI. Of the four wells showing decreased concentrations, the largest decrease occurred at LF05-19 where *cis*-1,2-DCE decreased by a factor of 15 from 280 to 18 $\mu\text{g/L}$. LF05-19 is the furthest downgradient well in the East Parking Lot TCE Plume. As shown in Figure II-14B of the RI, there is no obvious trend associated with the spatial distribution of increasing or decreasing *cis*-1,2-DCE concentrations. The largest increase in concentration occurred at HM-112, where *cis*-1,2-DCE increased from ND to 310 $\mu\text{g/L}$ in July 1992 (Figure II-14B of the RI).

In addition to TCE and its degradation products, 1,1,2-TCA, 1,1-DCA, 1,2-dichloropropane (DCP), methylene chloride, benzene, ethylbenzene, *o*-xylene, toluene, xylene, acetone, chlorobenzene, and chloroform were detected in concentrations exceeding the CRQL in upper-zone monitoring wells in the East Parking Lot Plume area. The concentrations at which these compounds were detected are listed in Table 1-86 and displayed in Figure II-15 of the RI.

As shown in Figure II-15 of the RI, the VOCs are concentrated in two regions. One region is adjacent to FDTA-5, south of Building 12, where monitoring wells W-131L and W-133L contain 1,100 $\mu\text{g/L}$ and 2,600 $\mu\text{g/L}$ chlorobenzene, respectively, 320 $\mu\text{g/L}$ and 1,900 $\mu\text{g/L}$ methylene chloride, respectively, and lesser amounts of benzene, toluene, ethylbenzene, and xylene. FDTA-5 is the most likely potential source for the VOC contamination identified in upper-zone groundwater in this area.

**Table 1-86. Upper-Zone Monitoring Wells Within the East Parking Lot Plume Area
Where Other VOC Concentrations Exceeded CRQLs**

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
1,1,2-Trichloroethane	LF04-02	LF04-02	27-Oct-91	3
1,1-Dichloroethane	LF04-02	LF04-02	27-Oct-91	1
1,1-Dichloroethane	W-139L	W-139L-01	16-Sep-91	9
1,2-Dichloropropane	W-131L	W-131L-01	11-Sep-91	8
Acetone	HM-024	HM-24-11	13-Nov-91	87
Acetone	HM-024	HM-24-12	13-Nov-91	87
Acetone	HM-115	QM-008	18-Mar-91	14
Acetone	HM-119	QM-021	18-Mar-91	12
Acetone	HM-125	QM-013	18-Mar-91	16
Acetone	W-131L	W-131L-01DL	11-Sep-91	150
Acetone	W-133L	W-133L-11	19-Oct-91	39
Acetone	W-155	W-155-01	18-Sep-91	22
Acetone	W-160	W-160-01	14-Sep-91	110
Acetone	W-160	W-160-01DL	14-Sep-91	150
Benzene	HM-090	NA-177	28-Apr-90	2,70E
Benzene	HM-056	NAA168	28-Apr-90	89
Benzene	W-131L	W-131L-01	11-Sep-91	38
Benzene	W-133L	W-133L-11	19-Oct-91	37
Benzene	W-139L	W-139L-01DL	16-Sep-91	280
Benzene	W-139L	W-139L-11DL	19-Oct-91	520
Benzene	W-141L	W-141L-01DL	16-Sep-91	730
Benzene	W-141L	W-141L-11DL	18-Oct-91	670
Benzene	W-160	W-160-01	14-Sep-91	15
Chlorobenzene	LF05-5A	LF05-5A	27-Oct-91	1
Chlorobenzene	W-131L	W-131L-01DL	11-Sep-91	1,100
Chlorobenzene	W-133L	W-133L-11D	19-Oct-91	2,600
Chloroform	HM-024	HM-24-11	13-Nov-91	51
Chloroform	HM-024	HM-24-12	13-Nov-91	52
Chloroform	HM-090	NAA177	29-Apr-90	18
Chloroform	LF04-02	LF04-02	27-Oct-91	1
Chloroform	LF05-01	LF05-01	28-Oct-91	2
Chloroform	W-131L	W-131L-01	11-Sep-91	8
Chloroform	W-133L	W-133L-11	19-Oct-91	5
Chloroform	WP07-10A	WP07-10A	27-Oct-91	1
Ethylbenzene	W-131L	W-131L-01	11-Sep-91	25
Ethylbenzene	W-133L	W-133L-11	19-Oct-91	25
Ethylbenzene	W-139L	W-139L-01DL	16-Sep-91	1,600
Ethylbenzene	W-139L	W-139L-11DL	19-Oct-91	3,500
Ethylbenzene	W-141L	W-141L-01DL	16-Sep-91	5,500
Ethylbenzene	W-141L	W-141L-11DL	18-Oct-91	5,200
Methylene Chloride	HM-047	NAA269	27-Apr-90	1,400
Methylene Chloride	W-128L	W-128L-01	12-Sep-91	9
Methylene Chloride	W-131L	W-131L-01DL	11-Sep-91	320
Methylene Chloride	W-133L	W-133L-11D	19-Oct-91	1,900

Table 1-86 (continued) Upper-Zone Monitoring Wells Within the East Parking Lot Plume Area Where Other VOC Concentrations Exceeded CRQLs

Chemical Name	Site ID	Sample ID	Sample Date	Result ($\mu\text{g/L}$)
Methylene Chloride	W-160	W-160-01	14-Sep-91	42
Methylene Chloride	W-160	W-160-01DL	14-Sep-91	57
<i>o</i> -Xylene	W-131L	W-131L-01	11-Sep-91	23
<i>o</i> -Xylene	W-133L	W-133L-11	19-Oct-91	21
<i>o</i> -Xylene	W-141L	W-141L-01	16-Sep-91	170
<i>o</i> -Xylene	W-141L	W-141L-11	18-Oct-91	120
Tetrachloroethene	LF04-02	LF04-02	27-Oct-91	23
Toluene	W-131L	W-131L-01	11-Sep-91	60
Toluene	W-133L	W-133L-11	19-Oct-91	57
Xylene	HM-090	NAA177	29-Apr-90	23
Xylene	W-131L	W-131L-01	11-Sep-91	73
Xylene	W-133L	W-133L-11	19-Oct-91	68
Xylene	W-139L	W-139L-01DL	16-Sep-91	500
Xylene	W-139L	W-139L-11	19-Oct-91	350
Xylene	W-141L	W-141L-01DL	16-Sep-91	12,000
Xylene	W-141L	W-141L-11D	18-Oct-91	10,000

Monitoring well HM-047 located approximately 300 feet downgradient of FDТА-5 also contained 1,2-dichlorobenzene at a concentration of 300J $\mu\text{g/L}$ and methylene chloride at a concentration of 1,400 $\mu\text{g/L}$. Further downgradient, monitoring well W-160 contained 15 $\mu\text{g/L}$ benzene, 150 $\mu\text{g/L}$ acetone, and 57 $\mu\text{g/L}$ methylene chloride. It is uncertain whether the contamination at W-160 is associated with FDТА-5. Monitoring well HM-090, located in the East Parking Lot, contains chloroform, benzene, and xylene at concentrations of 18 $\mu\text{g/L}$, 270E $\mu\text{g/L}$, and 23 $\mu\text{g/L}$, respectively. Evaluations of the groundwater contaminant distribution presented on Figure II-15 of the RI and water table elevations presented on Figure II-24 of the RI suggest that the contamination in monitoring well HM-90 may be originating from USTs 19 and 20 and FSA-1. These potential sources are located along the groundwater divide between the East Parking Lot Plume and West Plume areas where monitoring wells W-139L and W-141L are located. An easterly component of groundwater flow may transport contamination from FSA-1 to the East Parking Lot Plume. The path of that transport would lie directly below the main Assembly Building and could also explain the 89 $\mu\text{g/L}$ benzene detected in monitoring well HM-56.

The second area where VOC contamination, other than TCE, was detected was on CAFB (see Figure II-15 of the RI). VOC contamination was detected at monitoring wells HM-123, LF05-01, LF05-5A, LF05-02, WP07-10A, LF05-5C, LF04-02, and LF04-04 (see Figure II-15 of the RI). Volatile organic compounds were present in very low concentrations at these locations.

The results of sampling conducted after completion of the RI fieldwork (Jacobs Engineering Group, Inc. December 1992) showed no significant changes in the concentrations or distribution of VOCs.

East Parking Lot Plume: Semi-VOCs, TPH, and Oil and Grease

Semi-VOCs were detected in six monitoring wells in the East Parking Lot Plume area. A list of compounds detected in these wells is presented in Table 1-87. Monitoring wells W-131L, W-131U, and W-133L contained high concentrations of chlorobenzenes, naphthalenes, and di-n-butylphthalates, suggesting a potential source in close proximity, probably the DYCPs and FDТА-5. A map showing the locations of these monitoring wells is presented in Figure II-16 of the RI.

Semivolatile organic compounds detected in monitoring wells F-204, W-136, W-139L, and W-141L are probably derived from the source of fuel contamination at FSA-1. The semivolatile contamination at this location is located in an area of nearly flat hydraulic gradient. Consequently, the contamination in this area may eventually flow towards the East Parking Lot Plume or the West Plume area.

A summary of oil and grease and TPH monitoring in the East Parking Lot Plume is presented in Table 1-88. A posting of sampling locations and monitoring results for oil and grease and TPH is presented in Figure II-16 of the RI. Oil and grease and TPH in monitoring well F-218 were at the limit of detection at 0.2 mg/L. Oil and grease and TPH in monitoring wells HM-125, LF05-01 and W-131U were also very low. However, monitoring wells HM-104 and W-133L contained significant concentrations of oil and grease, and both oil and grease and TPH, respectively. In the vicinity of W-133L the potential source of these contaminants is possibly attributable to either the DYCP or the FDТА-5. The potential source in the vicinity of monitoring well HM-104 is unknown.

Oil and grease and TPH concentrations detected in monitoring wells F-204, W-136, W-139L, and W-141L are probably originating at FSA-1. The contamination in this area may eventually flow toward the East Parking Lot Plume or the West Plume area, depending on the exact location of the groundwater divide between these two areas.

The results of sampling conducted after completion of the RI field work (Jacobs Engineering Group, Inc. December 1992) showed no significant changes in the concentrations or distribution of semi-VOCs, TPH, or oil and grease.

West Plume: Volatile Organic Compounds

The second largest plume of groundwater contamination in the upper-zone flow system is referred to as the West Plume. This plume originates at the groundwater divide located within the west-central portion of the Assembly Building/Parts Plant and Building 14 (see Figure II-12 of the RI). The West Plume is a broad area of contaminated groundwater that spreads westward across Meandering Road toward Meandering Road Creek.

This plume may receive contamination from four potential sources. One important source of chlorinated organic solvent contamination is FDТА-2. Two potential sources of leachate contamination include Landfill No. 1 and Landfill No. 3. A fourth source is located between Building 14 and the Parts Plant, where fuel-related contamination may have been introduced from leaking fuel lines.

Table 1-87. Semi-VOCs Detected in the East Parking Lot Plume Area

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
Naphthalene	F-204	NAA284	26-Apr-90	56
2-Methylnaphthalene	F-204	NAA284	26-Apr-90	75
Naphthalene	F-204	NAA305	26-Apr-90	45
2-Methylnaphthalene	F-204	NAA305	26-Apr-90	62
1,2-Dichlorobenzene	W-131L	W-131L-11	19-Oct-91	88
1,4-Dichlorobenzene	W-131U	W-131U-01	12-Sep-91	12
1,2-Dichlorobenzene	W-131U	W-131U-01	12-Sep-91	81
1,4-Dichlorobenzene	W-131U	W-131U-02	12-Sep-91	12
Di-n-Butylphthalate	W-131U	W-131U-02	12-Sep-91	23
1,2-Dichlorobenzene	W-131U	W-131U-02	12-Sep-91	74
1,2-Dichlorobenzene	W-131U	W-131U-11	24-Oct-91	73
1,2-Dichlorobenzene	W-131U	W-131U-12	24-Oct-91	62
1,4-Dichlorobenzene	W-133L	W-133L-01	11-Sep-91	590
1,3-Dichlorobenzene	W-133L	W-133L-01	11-Sep-91	33
Naphthalene	W-133L	W-133L-01	11-Sep-91	16
2-Methylnaphthalene	W-133L	W-133L-01	11-Sep-91	24
1,2-Dichlorobenzene	W-133L	W-133L-01	11-Sep-91	2,000
1,4-Dichlorobenzene	W-133L	W-133L-11	19-Oct-91	370
1,2-Dichlorobenzene	W-133L	W-133L-11	19-Oct-91	1,300
Naphthalene	W-136	W-136-01	15-Sep-91	51
2-Methylnaphthalene	W-136	W-136-01	15-Sep-91	91
Naphthalene	W-136	W-136-11	18-Oct-91	12
2,4-Dimethylphenol	W-139L	W-139L-01	16-Sep-91	20
Naphthalene	W-139L	W-139L-01	16-Sep-91	77
2-Methylnaphthalene	W-139L	W-139L-01	16-Sep-91	79
Naphthalene	W-139L	W-139L-11	19-Oct-91	64
2-Methylnaphthalene	W-139L	W-139L-11	19-Oct-91	42
2,4-Dimethylphenol	W-141L	W-141L-01	16-Sep-91	130
Naphthalene	W-141L	W-141L-01	16-Sep-91	36
2-Methylnaphthalene	W-141L	W-141L-01	16-Sep-91	48
2,4-Dimethylphenol	W-141L	W-141L-11	18-Oct-91	79
Naphthalene	W-141L	W-141L-11	18-Oct-91	21
2-Methylnaphthalene	W-141L	W-141L-11	18-Oct-91	20
Bis(2-ethylhexyl)phthalate	W-160	W-160-01	14-Sep-91	13

Table 1-88. Oil and Grease and TPH Results in the East Parking Lot Plume Area

Chemical Name	Site ID	Sample ID	Sample Date	Result (mg/L)
Oil and Grease	F-204	NAA284	26-Apr-90	20.0
Oil and Grease	F-218	F-218	19-Oct-91	0.2
Total Petroleum Hydrocarbons	F-218	F-218	19-Oct-91	0.2
Oil and Grease	HM-104	QM-007	13-Mar-91	3.0
Oil and Grease	HM-125	QM-013	18-Mar-91	0.6
Oil and Grease	LF05-01	LF05-01	28-Oct-91	0.3
Oil and Grease	W-131U	W-131U-02	11-Sep-91	0.59
Oil and Grease	W-131U	W-131U-11	24-Oct-91	0.53
Oil and Grease	W-133L	W-133L-01	11-Sep-91	7.31
Total Petroleum Hydrocarbons	W-133L	W-133L-01	11-Sep-91	3.7
Oil and Grease	W-133L	W-133L-11	19-Oct-91	5.01
Total Petroleum Hydrocarbons	W-133L	W-133L-11	19-Oct-91	2.12
Total Petroleum Hydrocarbons	W-136	W-136-01	15-Sep-91	2.67
Total Petroleum Hydrocarbons	W-136	W-136-11	18-Oct-91	2.24
Total Petroleum Hydrocarbons	W-139L	W-139L-01	16-Sep-91	4.71
Total Petroleum Hydrocarbons	W-139L	W-139L-11	19-Oct-91	3.37
Total Petroleum Hydrocarbons	W-141L	W-141L-01	16-Sep-91	5.99
Total Petroleum Hydrocarbons	W-141L	W-141L-11	18-Oct-91	2.22

Groundwater in the West Plume flows towards Meandering Road Creek. Groundwater discharge to Meandering Road Creek is restricted by a bedrock high along Meandering Road Creek. However, a bedrock channel cuts the bedrock and provides a pathway to Meandering Road Creek.

The extent of the West Plume is defined by elevated concentrations of TCE, 1,2-DCA, 1,2-DCE, *cis*-1,2-DCE, vinyl chloride, 1,1,1-TCA, 1,1-DCA, 1,1-DCE, methylene chloride, PCE, benzene, ethylbenzene, *o*-xylene, toluene, xylene, 2-butanone, acetone, carbon disulfide, chlorobenzene, chloroform, and styrene. Most of these compounds were detected above their MCL during the RI (see Figures II-12 through II-16 of the RI).

In the vicinity of Building 217 and wells HM-30 and HM-41, the southwest boundary of the West Plume has not been defined. The most downgradient wells that were sampled in this area (HM-30 and HM-41) contained contamination. Monitoring wells located west of HM-30 and HM-41 were not sampled during the RI (in an effort to reduce analytical costs) so recent concentration data are not available.

TCE was the most prevalent VOC detected in the West Plume during the RI. TCE was detected at 14 monitoring wells. Upper-zone monitoring wells in the West Plume area that contained TCE at concentrations exceeding the CRQL are listed in Table 1-89. TCE concentrations exceeded the MCL of 5 $\mu\text{g/L}$ at each well. The highest TCE concentration reported in the West Plume occurred in monitoring well HM-51 (Figures II-12 and II-13 of the RI). Two samples collected from this monitoring well indicate TCE concentrations of 87,000 and 78,000 $\mu\text{g/L}$. This monitoring well is located within FDTA-2, which is a potential source for contamination of upper-zone groundwater.

Just west of the Parts Plant and between Buildings 14 and 88, there appears to be additional groundwater contamination by TCE (see Figures II-12 and II-13 of the RI). Three monitoring wells, HM-020, HM-029, and F-215 contained 240 $\mu\text{g/L}$, 1,400 $\mu\text{g/L}$ and 970 $\mu\text{g/L}$ TCE, respectively, in the upper-zone groundwater. The source of this contamination in the upper zone is probably FDTA-2. TCE concentrations in the remaining monitoring wells within the West Plume were relatively low. The low concentrations surrounded by relatively high point-concentrations suggests that advective transport is very slow as a result of the flat hydraulic gradient in this area. For example, monitoring well HM-29 is located in the transition zone between the East Parking Lot Plume and the West Plume area. Depending upon the exact location of the hydrologic divide, the advective transport may move the TCE towards either of the two plumes.

Degradation products of TCE were also identified within the West Plume. These compounds included 1,1-DCE, *cis*-1,2-DCE, *trans*-1,2-DCE (also reported as total 1,2-DCE), and vinyl chloride. Upper-zone monitoring wells in the West Plume area at which TCE degradation product concentrations exceeded CRQLs are listed in Table 1-90 and posted in Figure II-14 of the RI. The monitoring wells that contained the highest levels of TCE degradation products were HM-051, located near FDTA-2, and HM-021, located within Landfill No. 3. Samples collected from monitoring well HM-051 in April 1990 contained *cis*-1,2-DCE at a concentration of 80,000J $\mu\text{g/L}$. The "J" qualifier indicates the concentration could only be estimated as a result of the high concentrations of VOCs in the sample. Samples collected in monitoring well HM-021 in March 1991 contained up to 69,000 $\mu\text{g/L}$ 1,2-DCE and up to 6,500 $\mu\text{g/L}$ vinyl chloride. Monitoring well F-217, also located within Landfill No. 1, contained vinyl chloride at a concentration of 260 $\mu\text{g/L}$. Lower levels of 1,2-DCE were detected in monitoring wells F-215 and HM-010. *Cis*-1,2-DCE was detected at a concentration of 180 $\mu\text{g/L}$ in monitoring well W-129, located within Landfill No. 3. Potential sources for TCE and TCE-degradation products identified in the West Plume area include FDTA-2 and Landfills No. 1 and No. 3.

**Table 1-89. Upper-Zone Monitoring Wells in the West Plume Area
Where TCE Concentrations Exceeded the CRQL**

Site ID	Sample ID	Sample Date	Result (µg/L)
F-207	QM-001	19-Mar-91	9
F-207	QM-017	19-Mar-91	8
F-207	WQM001	05-Dec-90	13
F-215	QM-002DL	14-Mar-91	780
F-215	WQM002DL	05-Dec-90	970
F-216	NAA268	28-Apr-90	13
F-217	NAA156	02-May-90	10
F-217	NAA267	02-May-90	33
HM-010	NAA160	27-Apr-90	9
HM-010	QM-003	14-Mar-91	6
HM-010	WQM006	06-Dec-90	9
HM-020	NAA161	27-Apr-90	240
HM-020	NAA256	27-Apr-90	230
HM-021	QM-004	20-Mar-91	130
HM-029	NAA162	27-Apr-90	1,400
HM-050	NAA165	27-Apr-90	35
HM-051	NAA166	28-Apr-90	87,000
HM-051	NAA257	28-Apr-90	78,000
HM-063	NAA170	29-Apr-90	15
HM-066	NAA171	28-Apr-90	48
W-129	W-129-01	10-Sep-91	90
W-144	W-144-01	17-Sep-91	45
W-144	W-144-11D	17-Oct-91	150

Table 1-90 Upper-Zone Monitoring Wells Within the West Plume Area where TCE-Degradation Product Concentrations Exceeded CRQLs

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
1,1-Dichloroethene	F-207	NAA153	25-Apr-90	1,200
1,1-Dichloroethene	F-207	NAA259	25-Apr-90	1,100
1,1-Dichloroethene	F-207	NAA270	25-Apr-90	860
1,1-Dichloroethene	F-207	QM-001DL	19-Mar-91	930
1,1-Dichloroethene	F-207	QM-017DL	19-Mar-91	970
1,1-Dichloroethene	F-207	WQM001DL	05-Dec-90	700
1,1-Dichloroethene	F-215	QM-002	14-Mar-91	120
1,1-Dichloroethene	F-215	QM-002DL	14-Mar-91	110
1,1-Dichloroethene	F-215	WQM002	05-Dec-90	85
1,1-Dichloroethene	F-215	WQM002DL	05-Dec-90	83
1,1-Dichloroethene	F-217	NAA267	02-May-90	39
1,1-Dichloroethene	HM-010	QM-003	14-Mar-91	50
1,1-Dichloroethene	HM-010	WQM006	06-Dec-90	30
1,1-Dichloroethene	HM-020	NAA161	27-Apr-90	290
1,1-Dichloroethene	HM-020	NAA256	27-Apr-90	260
1,1-Dichloroethene	HM-021	QM-004	20-Mar-91	89
1,1-Dichloroethene	W-144	W-144-01DL	17-Sep-91	2,100
1,1-Dichloroethene	W-144	W-144-11D	17-Oct-91	1,100
1,2-Dichloroethene	F-215	QM-002	14-Mar-91	18
1,2-Dichloroethene	F-215	WQM002	05-Dec-90	16
1,2-Dichloroethene	HM-010	QM-003	14-Mar-91	74
1,2-Dichloroethene	HM-010	WQM006	06-Dec-90	11
1,2-Dichloroethene	HM-021	NAA102	27-Feb-90	280
1,2-Dichloroethene	HM-021	QM-004DL2	20-Mar-91	69,000
cis-1,2-Dichloroethene	W-129	W-129-01	10-Sep-91	160
cis-1,2-Dichloroethene	W-129	W-129-01DL	10-Sep-91	180
cis-1,2-Dichloroethene	W-132	W-132-01	10-Sep-91	25
cis-1,2-Dichloroethene	W-132	W-132-02	10-Sep-91	24
cis-1,2-Dichloroethene	W-132	W-132-11	23-Oct-91	9
cis-1,2-Dichloroethene	W-139L	W-139L-01	16-Sep-91	11
cis-1,2-Dichloroethene	W-139L	W-139L-11	19-Oct-91	9

Table 1-90 (continued) Upper-Zone Monitoring Wells Within West Plume Area where TCE-Degradation Product Concentrations Exceeded CRQLs

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
<i>cis</i> -1,2-Dichloroethene	W-132	W-132-02	10-Sep-91	24
<i>cis</i> -1,2-Dichloroethene	W-132	W-132-11	23-Oct-91	9
<i>cis</i> -1,2-Dichloroethene	W-139L	W-139L-01	16-Sep-91	11
<i>cis</i> -1,2-Dichloroethene	W-139L	W-139L-11	19-Oct-91	9
<i>trans</i> -1,2-Dichloroethene	W-132	W-132-01	10-Sep-91	8
<i>trans</i> -1,2-Dichloroethene	W-132	W-132-02	10-Sep-91	7
Vinyl Chloride	F-217	NAA100	27-Feb-90	260
Vinyl Chloride	HM-021	NAA102	27-Feb-90	980
Vinyl Chloride	HM-021	QM-004DL	20-Mar-91	5,600
Vinyl Chloride	HM-021	QM-004DL2	20-Mar-91	6,500

while others are fuel-related contaminants and intermediate products that may represent byproducts of the solvent compounds. VOCs other than TCE and its degradation products, identified during the RI include 1,1,1-TCA, 1,1-DCA, 1,2-DCA, methylene chloride, PCE, benzene, ethylbenzene, *o*-xylene, toluene, xylene, 2-butanone, acetone, carbon disulfide, chlorobenzene, chloroform, and styrene. Upper-zone monitoring wells in the West Plume area where concentrations of these compounds were reported above CRQLs are listed in Table 1-91 and shown in Figure II-15 of the RI.

Additional VOCs detected in well HM-051, located in FDTA-2, include methylene chloride (98,000 µg/L); 1,2-DCA (30,000 µg/L); and toluene (25,000 µg/L). The source of these compounds may have been seepage into the ground of incompletely combusted liquids used during fire training exercises.

High concentrations of benzene were detected at monitoring wells W-141L and W-139L, located between Building 14 and the Parts Plant. Plant 4 records indicate that fuel pipeline leakage has occurred in this area. Contamination reported in upper-zone groundwater at this location likely represents residual contamination from those leaks. Depending upon the precise location of the hydrologic divide, the benzene may either migrate towards the East Parking Lot Plume or the West Plume area.

Several VOCs were detected in monitoring wells HM-021 and W-132, located in Landfill No. 3. Elevated concentrations of 1,2-dichlorobenzene, vinyl chloride, 1,2-DCE, chlorobenzene, and 1,2-DCA were found in well HM-021. Styrene was detected in monitoring well W-132. The presence of these compounds further suggests that Landfill No. 3 may be a continuing source for groundwater contamination within the West Plume area of the upper-zone flow system.

**Table 1-91. Upper-Zone Monitoring Wells in the West Plume Area
Where Other VOC Concentrations Exceed CRQLs**

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
1,1,1-Trichloroethane	F-207	NAA259	25-Apr-90	380
1,1,1-Trichloroethane	F-207	NAA270	25-Apr-90	340
1,1,1-Trichloroethane	F-207	QM-001DL	19-Mar-91	200
1,1,1-Trichloroethane	F-207	QM-017	19-Mar-91	110
1,1,1-Trichloroethane	F-207	QM-017DL	19-Mar-91	240
1,1,1-Trichloroethane	F-207	WQM001	05-Dec-90	160
1,1,1-Trichloroethane	F-207	WQM001DL	05-Dec-90	150
1,1,1-Trichloroethane	F-215	QM-002	14-Mar-91	20
1,1,1-Trichloroethane	F-215	WQM002	05-Dec-90	15
1,1,1-Trichloroethane	F-217	NAA267	02-May-90	12
1,1,1-Trichloroethane	HM-010	QM-003	14-Mar-91	12
1,1,1-Trichloroethane	HM-010	WQM006	06-Dec-90	7
1,1,1-Trichloroethane	HM-020	NAA161	27-Apr-90	98
1,1,1-Trichloroethane	HM-020	NAA256	27-Apr-90	100
1,1,1-Trichloroethane	HM-021	QM-004	20-Mar-91	16
1,1,1-Trichloroethane	W-144	W-144-01	17-Sep-91	200
1,1,1-Trichloroethane	W-144	W-144-01DL	17-Sep-91	230
1,1,1-Trichloroethane	W-144	W-144-11	17-Oct-91	140
1,1,1-Trichloroethane	W-144	W-144-11D	17-Oct-91	120
1,1-Dichloroethane	F-207	QM-001	19-Mar-91	18
1,1-Dichloroethane	F-207	QM-017	19-Mar-91	18
1,1-Dichloroethane	F-207	WQM001	05-Dec-90	13
1,1-Dichloroethane	HM-021	QM-004	20-Mar-91	22
1,1-Dichloroethane	W-139L	W-139L-01	16-Sep-91	9
1,1-Dichloroethane	W-144	W-144-01	17-Sep-91	16
1,1-Dichloroethane	W-144	W-144-11	17-Oct-91	13
1,2-Dichloroethane	F-207	QM-001	19-Mar-91	57
1,2-Dichloroethane	F-207	QM-001DL	19-Mar-91	60
1,2-Dichloroethane	F-207	QM-017	19-Mar-91	60
1,2-Dichloroethane	F-207	QM-017DL	19-Mar-91	64
1,2-Dichloroethane	F-207	WQM001	05-Dec-90	30
1,2-Dichloroethane	F-207	WQM001DL	05-Dec-90	28
1,2-Dichloroethane	HM-051	NAA166	28-Apr-90	30,000
1,2-Dichloroethane	HM-051	NAA257	28-Apr-90	26,000
1,2-Dichloroethane	W-144	W-144-01	17-Sep-91	25
1,2-Dichloroethane	W-144	W-144-11	17-Oct-91	20
2-Butanone	F-217	NAA120	27-Mar-90	130
2-Butanone	HM-007	NAA101	27-Feb-90	10
2-Butanone	W-129	W-129-01DL	10-Sep-91	750
2-Butanone	W-132	W-132-02	10-Sep-91	13
Acetone	HM-021	QM-004	20-Mar-91	22

**Table 1-91. (continued) Upper-Zone Monitoring Wells in the West Plume Area
Where Other VOC Concentrations Exceed CRQLs**

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
Acetone	HM-021	QM-004DL2	20-Mar-91	7,600
Acetone	W-129	W-129-01	10-Sep-91	25
Benzene	HM-007	NAA121	27-Mar-90	7
Benzene	HM-007	NAA159	02-May-90	16
Benzene	HM-021	QM-004	20-Mar-91	33
Benzene	W-139L	W-139L-01DL	16-Sep-91	280
Benzene	W-139L	W-139L-11D	19-Oct-91	520
Benzene	W-141L	W-141L-01DL	16-Sep-91	730
Benzene	W-141L	W-141L-11D	18-Oct-91	670
Carbon Disulfide	W-136	W-136-11	18-Oct-91	20
Chlorobenzene	F-217	NAA156	02-May-90	14
Chlorobenzene	F-217	NAA267	02-May-90	21
Chlorobenzene	HM-007	NAA101	27-Feb-90	26
Chlorobenzene	HM-007	NAA159	02-May-90	6
Chlorobenzene	HM-021	NAA102	27-Feb-90	550
Chlorobenzene	HM-021	QM-004DL	20-Mar-91	350
Chloroform	HM-021	QM-004	20-Mar-91	90
Ethylbenzene	HM-007	NAA101	27-Feb-90	190
Ethylbenzene	HM-007	NAA118	27-Feb-90	480
Ethylbenzene	HM-007	NAA121	27-Mar-90	28
Ethylbenzene	HM-021	QM-004	20-Mar-91	88
Ethylbenzene	W-139L	W-139L-01DL	16-Sep-91	1,600
Ethylbenzene	W-139L	W-139L-11D	19-Oct-91	3,500
Ethylbenzene	W-141L	W-141L-01DL	16-Sep-91	5,500
Ethylbenzene	W-141L	W-141L-11D	18-Oct-91	5,200
Methylene Chloride	HM-051	NAA166	28-Apr-90	98,000
Methylene Chloride	HM-051	NAA257	28-Apr-90	83,000
<i>o</i> -Xylene	W-141L	W-141L-01	16-Sep-91	170
<i>o</i> -Xylene	W-141L	W-141L-11	18-Oct-91	120
Styrene	W-132	W-132-11	23-Oct-91	27
Tetrachloroethene	HM-021	QM-004	20-Mar-91	18
Tetrachloroethene	HM-050	NAA165	27-Apr-90	6
Toluene	HM-007	NAA101	27-Feb-90	71
Toluene	HM-021	QM-004	20-Mar-91	170
Toluene	HM-051	NAA166	28-Apr-90	25,000
Toluene	HM-051	NAA257	28-Apr-90	23,000
Xylene	HM-007	NAA101	27-Feb-90	16
Xylene	HM-007	NAA159	02-May-90	59
Xylene	HM-021	QM-004	20-Mar-91	75
Xylene	HM-090	NAA-177	29-Apr-90	23

**Table 1-91. (continued) Upper-Zone Monitoring Wells in the West Plume Area
Where Other VOC Concentrations Exceed CRQLs**

Chemical Name	Site ID	Sample ID	Sample Date	Result ($\mu\text{g/L}$)
Xylene	W-139L	W-139L-01DL	16-Sep-91	500
Xylene	W-139L	W-139L-11	19-Oct-91	350
Xylene	W-141L	W-141L-01DL	16-Sep-91	12,000
Xylene	W-141L	W-141L-11D	18-Oct-91	10,000

Monitoring wells completed in and around Landfill No. 1 indicate low levels of chlorinated compounds. The most prevalent VOCs, other than TCE and TCE-degradation products, identified in this area include PCE, 1,1,1-TCA, 1,1-DCA, 1,2-DCA, and chlorobenzene. Low concentrations of 2-butanone, acetone, and methylene chloride were also detected in several monitoring wells; however, these compounds may not be indicative of environmental contamination because these compounds are common laboratory contaminants.

Sampling conducted after completion of the RI field work (Jacobs Engineering Group, Inc. December 1992) did not include any upper-zone monitoring wells in the West Plume.

West Plume Area: Semi-VOCs, TPH, and Oil and Grease

Semi-VOCs were detected in five monitoring wells in the West Plume area. A list of compounds detected in these wells is presented in Table 1-92. Low levels of naphthalene, 2-methylnaphthalene, and 2,4-dimethylphenol were detected in monitoring wells F-204, W-136, W-139L, and W-141L. Each of these wells are located adjacent to FSA-1, the likely source of the semi-VOC contamination in this area. These constituents may eventually migrate east or west depending upon the location of the hydrologic divide.

Semi-VOCs were also detected in relatively high concentrations in monitoring well HM-021. The compounds 1,4-dichlorobenzene and 1,2-dichlorobenzene were detected at concentrations of 310 and 1,600 $\mu\text{g/L}$, respectively. Monitoring well HM-021 is located at Landfill No. 3, the potential source of the semi-VOC. A map showing the locations of each of the monitoring wells in the West Plume area is presented as Figure II-16 of the RI.

TPH and oil and grease were also detected in the West Plume area. A summary of the oil and grease and TPH monitoring for the West Plume is presented in Table 1-93. Monitoring wells F-204, W-136, W-139L, and W-141L, located in FSA-1, were found to contain significant levels of oil and grease and TPH. The source of this contamination is most likely FSA-1. A map showing the locations of these monitoring wells in the West Plume area is presented in Figure II-16 of the RI.

Sampling conducted after completion of the RI field work (Jacobs Engineering Group, Inc. December 1992) did not include any upper-zone monitoring wells in the West Plume.

**Table 1-92. Upper-Zone Monitoring Wells in the West Plume Area
Where Semi-VOC Concentrations Exceeded CRQLs**

261234

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
Naphthalene	F-204	NAA284	26-Apr-90	56
2-Methylnaphthalene	F-204	NAA284	26-Apr-90	75
Naphthalene	F-204	NAA305	26-Apr-90	45
2-Methylnaphthalene	F-204	NAA305	26-Apr-90	62
1,4-Dichlorobenzene	HM-021	QM-004	20-Mar-91	310
1,2-Dichlorobenzene	HM-021	QM-004	20-Mar-91	1,600
Naphthalene	W-136	W-136-01	15-Sep-91	51
2-Methylnaphthalene	W-136	W-136-01	15-Sep-91	91
Naphthalene	W-136	W-136-11	18-Oct-91	12
2,4-Dimethylphenol	W-139L	W-139L-01	16-Sep-91	20
Naphthalene	W-139L	W-139L-01	16-Sep-91	77
2-Methylnaphthalene	W-139L	W-139L-01	16-Sep-91	79
Naphthalene	W-139L	W-139L-11	19-Oct-91	64
2-Methylnaphthalene	W-139L	W-139L-11	19-Oct-91	42
2,4-Dimethylphenol	W-141L	W-141L-01	16-Sep-91	130
Naphthalene	W-141L	W-141L-01	16-Sep-91	36
2-Methylnaphthalene	W-141L	W-141L-01	16-Sep-91	48
2,4-Dimethylphenol	W-141L	W-141L-11	18-Oct-91	79
Naphthalene	W-141L	W-141L-11	18-Oct-91	21
2-Methylnaphthalene	W-141L	W-141L-11	18-Oct-91	20

**Table 1-93. Oil and Grease and TPH Analytical Results in the West Plume Area
(TPH and Oil and Grease were detected in Reportable Quantities)**

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
Oil and Grease	F-204	NAA284	26-Apr-90	20.0
Total Petroleum Hydrocarbons	W-136	W-136-01	15-Sep-91	2.67
Total Petroleum Hydrocarbons	W-136	W-136-11	18-Oct-91	2.24
Total Petroleum Hydrocarbons	W-139L	W-139L-01	16-Sep-91	4.71
Total Petroleum Hydrocarbons	W-139L	W-139L-11	19-Oct-91	3.37
Total Petroleum Hydrocarbons	W-141L	W-141L-01	16-Sep-91	5.99
Total Petroleum Hydrocarbons	W-141L	W-141L-11	18-Oct-91	2.22

North Plume: Organic Contamination

Upper-zone groundwater in the North Plume area is part of the groundwater flow system that originates along a hydrologic divide that trends east to west across the north end of the Main Assembly Building (see Figure II-24 of the RI). Analytical results for upper-zone groundwater in this area indicate that monitoring wells F-209 and W-135 contain VOC concentrations greater than CRQLs. A list of the VOCs that exceeded CRQLs in these two monitoring wells is presented in Table 1-94. Well locations and monitoring results are presented in Figures II-12, -13, -14, and -15 of the RI.

Table 1-94. Upper Zone Monitoring Wells in the North Plume Area Where VOC Concentrations Exceeded CRQLs

Chemical Name	Site ID	Sample ID	Sample Date	Result (µg/L)
1,1,2-Trichloroethane	F-209	NAA302	26-Apr-90	660
1,1-Dichloroethane	F-209	NAA302	26-Apr-90	620
1,2-Dichloropropane	F-209	NAA302	26-Apr-90	610
2-Butanone	W-135	W-135-01	14-Sep-91	69
2-Butanone	W-135	W-135-11	22-Oct-91	120
Carbon Tetrachloride	F-209	NAA302	26-Apr-90	400
Chlorobenzene	F-209	NAA302	26-Apr-90	590
Chloroform	F-209	NAA302	26-Apr-90	620
Dibromochloromethane	F-209	NAA302	26-Apr-90	550
Methylene Chloride	F-209	NAA302	26-Apr-90	610
Tetrachloroethene	F-209	NAA302	26-Apr-90	450
Trichloroethene	F-209	NAA302	26-Apr-90	530

Analytical results for monitoring well F-209 indicate 530 µg/L TCE, 450 µg/L PCE, 610 µg/L methylene chloride, 550 µg/L dibromochloromethane, 620 µg/L chloroform, 590 µg/L chlorobenzene, 400 µg/L carbon tetrachloride, 610 µg/L 1,2-dichloropropane, 620 µg/L 1,1-DCA, and 660 µg/L 1,1,2-TCA. Monitoring well W-135 was sampled in September 1991 and October 1991; on both occasions 2-butanone was detected. Although 2-butanone is a common laboratory contaminant, the laboratory reports did not indicate laboratory blank contamination. The source of the VOC contamination reported in these monitoring wells is unknown.

Results of previous investigation (Hargis + Associates 1988) indicated that monitoring wells in the vicinity of the North Plume area, including F-201, F-202, F-209, F-210, F-222 and F-223 each contained varying thicknesses of LNAPL at the water table. Thicknesses of the floating material ranged from a mere sheen to greater than 1 foot. During the RI, a sample of the LNAPL was collected from monitoring well FSA-3-11 and submitted for analysis. Samples of diesel No. 2, fuel oil No. 2, unleaded gasoline, JP-4, and JP-5 were also submitted for use as comparison standards. The peak profile for the sample from FSA-3-11 most closely resembled the peak profile obtained for JP-4. The source of the floating product contamination in the North Plume area is suspected to be the fuel lines extending to the jet engine test facility.

Sampling conducted after completion of the RI field work (Jacobs Engineering Group, Inc. December 1992) did not include any upper-zone monitoring wells in the North Plume.

North Plume: Semi-VOCs, TPH, and Oil and Grease

Semi-VOCs were detected in two monitoring wells, F-209 and HM-107. Monitoring well F-209 contained 16 $\mu\text{g/L}$ of 2-methylnaphthalene, which is a fuel component. Monitoring well HM-107 contained 12 $\mu\text{g/L}$ of bis(2-ethylhexyl)phthalate, a common laboratory contaminant. A potential source of the 2-methylnaphthalene is leaking fuel supply lines and storage tanks surrounding the JETS. The two monitoring wells that contained these contaminants are listed in Table 1-95 and shown on Figure II-16 of the RI.

Table 1-95. Analytical Results of Semi-VOCs Detected Above CRQLs in the North Plume Area

Chemical Name	Site ID	Sample ID	Sample Date	Result ($\mu\text{g/L}$)
2-Methylnaphthalene	F-209	NAA302	26-Apr-90	16
Bis(2-ethylhexyl)phthalate	HM-107	HM-107-01	15-Sep-91	12

A summary of the oil and grease and TPH monitoring results in the North Plume area is presented in Table 1-96. Monitoring well F-209 contained 11 mg/L oil and grease, while monitoring well HM-107 contained 12 mg/L TPH. The source for oil and grease and TPH in this location may be attributable to leaking lines and storage tanks near the JETS. A map showing the locations of both monitoring wells F-209 and HM-107 is presented in Figure II-16 of the RI.

Table 1-96. Oil and Grease and TPH Analytical Results in the North Plume Area

Chemical Name	Site ID	Sample ID	Sample Date	Result
Oil and Grease	F-209	NAA302	26-Apr-90	11
Total Petroleum Hydrocarbons	HM-107	HM-107-01	15-Sep-91	12

1.5.5.2 Upper-Zone Groundwater: Inorganic Contamination

Water samples collected during the 1990-1991 monitoring events from wells in the upper-zone flow system were analyzed for selected inorganic chemicals, including those on the EPA priority-pollutant list. Results of the analyses are summarized in Table 1-97 and presented in Appendix F of the RI. The action levels listed in Table 1-97 refer to the EPA MCL or the secondary maximum contaminant level (SMCL) (EPA drinking water standards). For purposes of comparison, the number of samples that were found to exceed the action level are tabulated.

Seven priority pollutants, including antimony, arsenic, cadmium, chromium, lead, nickel, and thallium, were all detected above their respective action levels. The action level was exceeded for chromium in 12 samples, for lead in nine samples, for arsenic in three samples, and for the remaining analytes in one sample. In addition to the priority pollutants, aluminum and iron exceeded the secondary drinking water standards in 25 samples and manganese in 13 samples. Table 1-98 lists all the samples that were found to exceed drinking water standards.

Figure II-17 of the RI shows analytical results of inorganic priority pollutants, excluding chromium. Chromium results are shown in Figure II-18 of the RI. The posted results are based on samples collected from new wells that were installed and monitored during the 1990-1991 RI in addition to the results for samples that were collected by previous contractors for the 1988-1991 monitoring period. In all cases, the values reported are the most recent analytical results available during the 1988-1991 monitoring period.

Examination of Figure II-17 of the RI reveals that zinc and copper occur widespread over the area, including the East Parking Lot Plume, the West Plume, and the North Plume. However, these values are relatively low in concentration and in all cases are less than the secondary standards. Analytes that were detected at concentrations exceeding drinking water standards in the upper-zone flow system are described below.

East Parking Lot Plume

Monitoring wells W-133L and CAR-LF05-02, located near the western and southeastern margin of the East Parking Lot Plume area, respectively, contain arsenic at concentrations in excess of the MCL (see Figure II-17 of the RI). Arsenic was detected at a concentration of 72.8 $\mu\text{g/L}$ in well W-133L, slightly above the 250 $\mu\text{g/L}$ MCL. The possible source area for arsenic is the FDTA-5. Arsenic was detected in monitoring well CAR-LF-05-02 at a concentration of 53 $\mu\text{g/L}$. This well is located on CAFB at the southeastern margin of the East Parking Lot Plume.

**Table 1-97. Results of Inorganic Analyses for Upper-Zone Groundwater
Collected During the 1990-1991 Sampling Events**

Chemical Name	Minimum Result (µg/L)	Maximum Result (µg/L)	Action Level (µg/L)	Number of Samples Analyzed	Number of Samples Above Action Level
Aluminum ^a	100	13,500	NA	29	NA
Antimony ^b	56U ^c	100	10	84	1
Arsenic ^d	3U	134	50	84	3
Barium ^b	100U	980	2,000	29	0
Beryllium ^d	1U	5U	1	84	0
Cadmium ^a	2U	5.9	5	84	1
Calcium	66,000	592,000	NA	41	NA
Chromium ^b	5U	1,040	100	105	12
Cobalt	50U	50U	NA	29	NA
Copper ^a	5U	130	NA	84	NA
Cyanide ^b	0.01U	17	200	10	0
Iron ^a	16U	14,000	NA	41	NA
Lead ^f	2U	140	15	84	9
Magnesium	2,500	54,500	NA	41	NA
Manganese ^a	15U	750	NA	29	NA
Mercury ^a	0.2U	0.3	2	29	0
Nickel ^b	22U	113	100	85	1
Potassium	938U	64,000	NA	41	NA
Selenium ^a	3U	2.1B ^g	50	84	0
Silver ^a	4U	10U	NA	84	NA
Sodium	12,000	797,000	NA	41	NA
Thallium ^b	2U	2.8B	2	84	1
Vanadium	50U	50U	NA	29	NA
Zinc ^a	7U	3,860	NA	84	NA

^a No action level exists for this chemical because it is regulated by secondary standards.

^b Action level for this chemical is the Maximum Contaminant Level (MCL) (FR V.57 No. 138).

^c U indicates the chemical was not detected.

^d Action level for this chemical is the MCL (40 CFR 141.11).

^e Action level for this chemical is the MCL (FR. V.56 No. 20).

^f Action level for this chemical is the MCL (FR. V.56 No. 110).

^g B indicates the result is above or equal to the IDL but less than the Contract Required Detection Limit.

**Table 1-98. Summary of Inorganic Analytes that Exceeded the Action Level
in Samples Collected from Upper-Zone Groundwater During the
1990-1991 Sampling Events**

Chemical Name	Well ID	Sample ID	Date Sampled	Result (µg/L)
Antimony	F-217	NAA156	02-May-90	100
Arsenic	W-133L	W-133L-11	19-Oct-91	72.8
	F-204	NAA284	26-Apr-90	79
	W-133L	W-133L-01	11-Sep-91	134
Cadmium	F-217	NAA156	02-May-90	5.9
Chromium	HM-029	NAA162	27-Apr-90	105
	F-215	QM-002	14-Mar-91	113
	HM-096	NAA182	25-Apr-90	142
	F-215	WQM002	05-Dec-90	151
	W-159	W-159-11	20-Oct-91	164
	W-159	W-159-01	14-Sep-91	188
	HM-094	NAA180	29-Apr-90	380
	F-218	F-218	19-Oct-91	400
	W-149	W-149-01	18-Sep-91	578
	W-149	W-149-11	17-Oct-91	629
	W-154	W-154-11	20-Oct-91	838
	W-154	W-154-01	14-Sep-91	1030
	W-154	W-154-02	14-Sep-91	1040
Lead	W-137	W-137-01	16-Sep-91	15.4
	W-149	W-149-11	17-Oct-91	17.1
	HM-020	NAA256	27-Apr-90	18
	W-150L	W-150L-01	14-Sep-91	19.3
	HM-020	NAA161	27-Apr-90	22
	HM-094	NAA180	29-Apr-90	29
	HM-024	HM-24-11	13-Nov-91	53.5
	HM-086	NAA173	28-Apr-90	100
	F-217	NAA156	02-May-90	140
Nickel	W-150L	W-150L-01	14-Sep-91	113
Thallium	W-131U	W-131U-02	12-Sep-91	2.8B*

* B indicates the result is above or equal to the IDL but less than the CRDL.

Thallium was detected at a concentration of 2.8B µg/L in monitoring well W-131U, also located in the FDTA-5. The B qualifier for this value indicates that the concentration is greater than the IDL but less than the CRDL. This qualified value is only slightly above the 2 µg/L MCL.

Lead concentrations in the East Parking Lot Plume that are above the 15 µg/L MCL (at the tap) range from 15.4 to 100 µg/L. These values were measured from samples collected from a monitoring well completed in Chrome Pit No. 3 (W-150L), a well east of the DYCP (HM-24), and in a well adjacent

to the WWCB (W-137). Lead values above the MCL also occur in monitoring wells HM-86, HM-94, and W-149, located near the center of the East Parking Lot Plume area, and in wells CAR-LF-05-01 and CAR-LF05-14, located near the southeastern margin of the East Parking Lot Plume area on CAFB.

Nickel was detected in the water sample collected from monitoring well W-150L at a concentration of 113 $\mu\text{g/L}$, which is above the 100 $\mu\text{g/L}$ MCL. This well is located in Landfill No. 1, the probable source for this analyte.

Seven monitoring wells reported chromium concentrations in excess of the 100 $\mu\text{g/L}$ MCL (see Figure II-18 of the RI). The majority of these wells, W-159, F-218, W-149, HM-94, and HM-96 are located near the center of the East Parking Lot Plume and downgradient from Chrome Pits Nos. 1 and 2, which may be possible source areas. The distribution of the chromium values in the plume appear to be controlled by geometry of the buried paleochannel. The highest chromium value, 1,040 $\mu\text{g/L}$, was detected at monitoring well W-154, located near the most upgradient extent of the East Parking Lot Plume. The well is adjacent to Chrome Pit No. 3, which is a potential source area for chromium. The most downgradient well having a chromium value (200 $\mu\text{g/L}$) exceeding the MCL is CAR-FT08-11B, located near the southeastern extent of the plume on CAFB. However, the presence of chromium was not detected in this well during the subsequent monitoring campaign.

Only two of the upper-zone wells included in the post-RI sampling program contained priority-pollutant metals. HM-103 contained 22 $\mu\text{g/L}$ of lead, and F-218 contained 310 $\mu\text{g/L}$ of chromium. The chromium concentration of 310 $\mu\text{g/L}$ in F-218 is consistent with the 400 $\mu\text{g/L}$ concentration found during the RI (Figure II-18 of the RI). HM-103 had not been sampled previously so no conclusions can be drawn regarding the lead contamination. Because the distribution of priority pollutant metals in upper-zone groundwater is limited and only a small number of wells were included in the post-RI sampling, no significant assessment of metals migration after the RI field work is possible.

West Plume

Cadmium and antimony were detected in monitoring well F-217 at concentrations of 5.9 and 100 $\mu\text{g/L}$, respectively (see Figure II-17 of the RI). The possible source area for these analytes is Landfill No. 1. Lead was detected in the Landfill No. 1 area at concentrations of 22 and 140 $\mu\text{g/L}$ in HM-020 and F-27, respectively (Figure II-17). Arsenic was detected in F-204 at a concentration of 79 $\mu\text{g/L}$ (Figure II-17). F-204 is located near the site of former storage tanks UST Nos. 19 and 20. Chromium was detected at a concentration of 151 $\mu\text{g/L}$ in well F-215 and at 105 $\mu\text{g/L}$ in well HM-29 (Figure II-18 of the RI). These wells are located between Buildings 14 and 88, just east of Landfill No. 1.

North Plume Area

Arsenic was detected in monitoring well W-134 at a concentration of 19.5 $\mu\text{g/L}$, which is below the MCL (see Figure II-17 of the RI). This well is located just south of the JETS, which is a potential source area for arsenic. No metals, including chromium, were detected above the MCL in the North Plume area (see Figure II-18 of the RI).

1.5.5.3 Paluxy Formation Groundwater: Organic Contamination

Volatile Organic Compounds

VOCs reported above the CRQL in groundwater samples collected from wells completed within the Paluxy Formation include TCE, *cis*- and *trans*-1,2-DCE, vinyl chloride, toluene, methylene chloride, 1,1-DCA, 1,2-DCA, 2-hexanone, and chloroform. These compounds are primarily found in the upper part of the flow system where vertical hydraulic gradients and downward flow components exist between the upper zone and the Paluxy Formation. The VOCs present in the Paluxy Formation are considered to be attributable to vertical leakage from the upper-zone flow system. A summary of VOCs detected above CRQLs in Paluxy Formation groundwater is presented in Table 1-99.

Table 1-99. VOCs Detected at Concentrations Above CRQLs in Paluxy Formation Groundwater

Chemical Name	Minimum ($\mu\text{g/L}$)	Maximum ($\mu\text{g/L}$)	MCL ($\mu\text{g/L}$)	Number of Samples	Number of Samples Exceeding CRQL	Number of Samples Exceeding MCL
Trichloroethene	1U	11,000	5	79	25	24
1,1-Dichloroethane	1U	20	—	79	2	—
Methylene Chloride	1U	2,500	5	79	3	3
Vinyl Chloride	2U	22	2	79	2	2
Chloroform	1	1	100	79	1	0
2-Hexanone	2U	2,200	—	63	1	—
1,2-Dichloroethene	5U	390	—	46	4	—
<i>trans</i> -1,2-Dichloroethene	1U	2	100	33	1	0
<i>cis</i> -1,2-Dichloroethene	1U	940	70	33	8	6
Toluene	1U	800	3000	79	5	0
1,2-Dichloroethane	1U	1,500	5	63	1	1

Contamination in the Paluxy Formation may be grouped into three categories: TCE; degradation products of TCE, such as *cis*- and *trans*-1,2-DCE, and vinyl chloride; and other organics that include methylene chloride, toluene, 2-hexanone, chloroform, and 1,1-DCA.

TCE was the most commonly encountered VOC in Paluxy Formation groundwater. Monitoring wells in which TCE was detected above the CRQL during the RI are presented in Table 1-100. TCE was also detected in two equipment blanks (see Section 1.5.2) at concentrations of 5J $\mu\text{g/L}$ and 11 $\mu\text{g/L}$. The TCE data presented in Table 1-100 and data collected by others were combined to prepare a map showing the approximate extent of elevated TCE concentrations in Paluxy Formation groundwater (see Figures II-19a through d of the RI). This map depicts two areas with elevated TCE concentrations in groundwater. The largest area encompasses the East Parking lot; the second area is located northwest of Building 14.

**Table 1-100 Paluxy Formation Monitoring Wells
Where TCE Was Detected Above CRQLs**

Well ID	Sample ID	Sample Date	TCE ($\mu\text{g/L}$)
P-05M	NAA206	28-Apr-90	14
P-08UN	NAA266	28-Apr-90	22
P-08UN	P-8UN	19-Oct-91	30
P-08US	NAA213	29-Apr-90	550
P-08US	P-08US2/04/92D	04-Feb-92	210
P-08US	P-08US1/26/93D	26-Jan-93	1900
P-08US	P-08US6/10/93	10-Jun-93	3000
P-08US	P-08US1/23/94	23-Jan-94	950
P-08US	P-08US7/23/94	23-Jul-94	1700
P-09US	NAA215	29-Apr-90	4,300
P-09US	WQM005	05-Dec-90	1,900
P-09US	QM-014	13-Mar-91	980
P-09US	P-09US10/20/91A	20-Oct-91	300
P-09US	P-09US	02-Feb-92	400
P-09US	P-09US7/27/92A	27-Jul-92	200
P-09US	P-09US7/27/92B	27-Jul-92	240
P-09US	P-09US7/27/92C	27-Jul-92	289
P-09US	P-09US7/27/92D	27-Jul-92	299.5
P-09US	P-09US7/27/92E	27-Jul-92	310
P-09US	P-09US	26-Jan-93	200
P-09US	P-09USD	26-Jan-93	240
P-09US	P-09US6/08/93	08-Jun-93	1000
P-09US	P-09US1/22/94	22-Jan-94	210
P-09US	P-09US7/22/94	22-Jul-94	8.4
P-10M	NAA217	30-Apr-90	13
P-12M	AFR-005	12-Jun-91	3
P-12M	NAA221	29-Apr-90	7
P-14US	NAA225	02-May-90	320
P-14US	P-14US2/04/92	04-Feb-92	2100
P-14US	P-14US7/29/92	29-Jul-92	230
P-14US	P-14US	26-Jan-93	200
P-14US	P-14US5/25/93	25-May-93	130
P-14US	P-14US1/23/94A	23-Jan-94	150
P-14US	P-14US1/23/94B	23-Jan-94	150
P-14US	P-14US7/26/94	26-Jul-94	130
P-15US	NAA226	02-May-90	40
P-15US	P-15US1/31/92	31-Jan-92	430
P-15US	P-15US5/24/93A	24-May-93	1600

**Table 1-100 (continued) Paluxy Formation Monitoring Wells
Where TCE Was Detected Above CRQLs**

Well ID	Sample ID	Sample Date	TCE ($\mu\text{g/L}$)
P-15US	P-15US5/24/93B	24-May-93	1680
P-15US	P-15US5/24/93C	24-May-93	1690
P-16US	NAA228	02-May-90	860
P-16US	WQM021	09-Dec-90	900
P-16US	P-16US	26-Oct-91	510
P-16US	QM-016	13-Mar-91	780
P-16US	P-16US	31-Jan-92	1100
P-16US	P-16US	28-Jul-92	1000
P-16US	P-16US	26-Jan-93	950
P-16US	P-16US5/24/93	24-May-93	750
P-16US	P-16US1/24/94	24-Jan-94	1000
P-16US	P-16US7/26/94	26-Jul-94	680
P-19US	P-19US1/31/92	31-Jan-92	8400
P-19US	P-19US	28-Apr-92	8900
P-19US	P-19US7/29/92	29-Jul-92	8500
P-19US	P-19US1/26/93	26-Jan-93	11000
P-19US	P-19US10/09/93	09-Oct-93	7100
P-19US	P-19US1/24/94	24-Jan-94	9000
P-19US	P-19US7/26/94A	26-Jul-94	8400
P-19US	P-17/26/949USB	26-Jul-94	9200
P-22M	NAA275	01-May-90	10
P-22M	P-22M	22-Oct-91	2
P-22M	WQM015	08-Dec-90	7
P-22U	NAA230	01-May-90	90
P-22U	NAA264	01-May-90	69
P-22U	P-22UPPER	27-Jan-90	100
P-22U	WQM017	08-Dec-90	48
P-24M	NAA233	30-Apr-90	8
P-27U	P27U-11	18-Oct-91	69
P-27U	P27U-11D	18-Oct-91	74

Within the East Parking Lot area only P-9US contained TCE at a concentration exceeding 1,000 $\mu\text{g/L}$ during the RI sampling. Other Paluxy wells in the East Parking Lot had lower TCE concentrations ranging from 100 to 1,000 $\mu\text{g/L}$.

TCE was also detected in the groundwater northwest of Building 14. One monitoring well (P-22U) contained TCE in concentrations approaching 100 $\mu\text{g/L}$. However, TCE concentrations in this area were generally lower than concentrations in the East Parking Lot area (0.2J $\mu\text{g/L}$ for well P-6M to

10 $\mu\text{g/L}$ for well P-22M, and 74 $\mu\text{g/L}$ for well P-27U). TCE was not detected in the remaining monitoring wells completed in the Paluxy Formation.

The TCE detected in P-22U and P-27U defines what is referred to as the West Paluxy Plume (Figures II-19b and II-19d of the RI). Given the presence of 25 feet of Walnut Formation present at this location, leakage through the aquitard had not been regarded as a likely source for the West Paluxy Plume. However, during fieldwork conducted in the spring of 1995, the surface completion of P-22M was found to be loose, suggesting a lack of or incomplete placement of annular grout. The well has recently been abandoned.

As shown in Table 1-100 and Figure II-19a through d of the RI, occurrences of TCE were most commonly observed in the uppermost portion of the Paluxy Formation, referred to as the Upper Sand. However, low concentrations of isolated occurrences of TCE were also reported in wells completed in the regional Paluxy aquifer. Within the East Parking Lot area, deeper monitoring wells at which low TCE concentrations were detected included wells P-8UN and P-12M. West of the Assembly Building, monitoring wells P-5M, P-10M, P-22M, and P-24M contained low concentrations of TCE. These occurrences suggest that TCE contamination may be migrating to deeper zones within the Paluxy Formation. Contamination at P-10M carries the implication that the contamination may be originating as seepage from Meandering Road Creek. Monitoring well P-10M was resampled twice during post-RI sampling (Jacobs Engineering Group, Inc. December 1992) to determine if TCE was still present. TCE was detected at 0.1 JB $\mu\text{g/L}$ (also found in the blank) in October 1991. TCE was not detected in P-10M during the October 1992 sampling event.

The results of post-RI sampling at other Paluxy Formation wells showed little change at P-8UN, P-16US, and P-22M. Decreasing concentrations were observed at P-9US (from 4,300 $\mu\text{g/L}$ in 1990 to 8.4 $\mu\text{g/L}$ in July 1994), P-14US (2,100 $\mu\text{g/L}$ in January 1992 to 130 $\mu\text{g/L}$ in July 1994), and P-27U (from 74 $\mu\text{g/L}$ in 1992 to 16 $\mu\text{g/L}$ in July 1994).

The declining trend at P-09US is noteworthy in the sense that the origin of TCE observed in this well has always been somewhat elusive. Water levels at P-09US have consistently exceeded those of all other Upper Sand wells. This feature precludes attributing the P-09US contamination to lateral migration of TCE that entered via the window area. The current low concentrations in the Upper Zone also preclude the hypothesis involving ongoing vertical migration along the well bore. The declining trend in TCE at P-09US suggests that the contamination may have been introduced to the Paluxy via vertical migration through the open hole during the installation of the well. However, the presence of a source for the vertical migration at the time of installation, namely Upper Zone TCE contamination at levels equal to or above the historic maximum at P-09US (7,000 $\mu\text{g/L}$ in October 1989) is questionable, given the low or nonexistent concentrations in nearby HM-5U and HM-57 (see Figures II-12A, II-12B, II-13a and II-13b of the RI).

Noteable increases in TCE concentrations occurred at P-8US, P-15US, and P-19US. The TCE concentration at P-8US increased from 550 $\mu\text{g/L}$ in April 1990 to 1,900, 3,000, 950, and 1,700 $\mu\text{g/L}$ in January 1993, June 1993, January 1994, and July 1994, respectively. Similarly, P-15US increased from 40 $\mu\text{g/L}$ in May 1990 to over 1,600 $\mu\text{g/L}$ in May 1993. These increases can likely be attributed to renewed vertical leakage of TCE-contaminated groundwater in the window area. Alternatively, the increase in TCE at P-08US and P-15US could simply reflect the arrival of laterally migrating TCE that had entered the Paluxy Upper Sand via the window area at some point in the past. TCE in

P-19US ranged from 8,400 to 8,900 $\mu\text{g/L}$ between January and July 1992. In January 1993, the concentration increased to 11,000 $\mu\text{g/L}$ then declined to 8,400 and 9,200 $\mu\text{g/L}$ in July 1994.

The contamination at P-19US is noteworthy for two reasons. The concentrations are the highest detected in any of the Upper Sand wells, and P-19US has historically been dry, only recently providing sufficient water from which to collect a sample (after purging only one bore volume). The contamination at P-19US is likely derived via one or a combination of four scenarios. The TCE could be entering the Upper Sand through a undocumented thin or absent section of the Walnut Formation in the vicinity of P-19US. Similar to P-22M, contamination could be migrating downward along an improperly completed well installation (at P-19US). The weakness in these first two hypotheses is that nearby Upper Zone wells (HM-110, HM-111, and HM-112) do not show the Upper Zone containing high enough concentrations to be acting as a source for the 8,000 to 11,000 $\mu\text{g/L}$ concentrations in P-19US (Figures II-12A, II-12B, II-13A, and II-13B of the RI).

A third possibility is that the contamination observed at P-19US entered the Upper Sand in the window area prior to initiation of environmental sampling and travelled to the P-19US area via lateral-downgradient advection (head at P-19US is approximately 20 to 30 feet lower than Upper Sand head in the window area; see Appendix D).

The last explanation for the source of high TCE concentrations at P-19US is that the contamination entered the Upper Sand during drilling, and has essentially remained in this area due to the low permeability, aquitard-like behavior of the Upper Sand. Variations in concentration from a low of 7,100 $\mu\text{g/L}$ in October 1993 to a high of 11,000 $\mu\text{g/L}$ in January 1993 are not necessarily inconsistent with this scenario, although a declining trend would be more compatible with this fourth hypothesis.

Degradation products of TCE, including *cis*- and *trans*-1,2-DCE and vinyl chloride, were detected above CRQLs in approximately the same two areas that were found to contain elevated TCE. None of these compounds were detected in the equipment blank samples. Results for DCE and vinyl chloride are presented in Table 1-101. The monitoring data collected by others were combined with the recent data to compile a map of TCE degradation products within the Paluxy Formation (see Figure II-20 of the RI).

Within the upper part of the Paluxy Formation near the East Parking Lot, analytical results for samples collected in October 1991 indicated that well P-16US contained 290 $\mu\text{g/L}$ *cis*-1,2-DCE and 2 $\mu\text{g/L}$ *trans*-1,2-DCE, and that well P-08UN contained 4 $\mu\text{g/L}$ *cis*-1,2-DCE. Prior to the October 1991 sampling event, 1,2-DCE was reported as total 1,2-DCE. For example, total 1,2-DCE was 390 $\mu\text{g/L}$ in March 1991 and 360 $\mu\text{g/L}$ in December 1990 in well P-16US. Well P-09US contained 21 $\mu\text{g/L}$ total 1,2-DCE in December 1990.

High concentrations of *cis*-1,2-DCE are reported for P-19US starting in January 1992. Prior to this date, P-19US was not sampled because it only contained a few inches of water and could not be properly purged. Since 1992, samples collected by the sampling contractor have shown very high elevations of TCE as well as the DCE reported in Table 1-101. The DCE detected in P-19US is likely derived from natural degradation of TCE at this location.

**Table 1-101 TCE Degradation Products Detected
in Paluxy Formation Groundwater**

Well ID	Sample ID	Sample Date	Chemical Name	Result (µg/L)
P-06M	P-6M	26-Oct-91	Vinyl Chloride	5
P-06M	P-6M	26-Oct-91	<i>cis</i> -1,2-Dichloroethene	11
P-08US	P-08US2/4/92	04-Feb-92	<i>cis</i> -1,2-Dichloroethene	32
P-08US	P-08US6/9/93	09-Jun-93	<i>cis</i> -1,2-Dichloroethene	140
P-08US	P-08US1/22/94	22-Jan-94	<i>cis</i> -1,2-Dichloroethene	120
P-08US	P-08US7/23/94	23-Jul-94	<i>cis</i> -1,2-Dichloroethene	120
P-08UN	P-8UN	19-Oct-91	<i>cis</i> -1,2-Dichloroethene	4
P-09US	WQM005	05-Dec-90	1,2-Dichloroethene	21
P-09US	P-09US6/8/93	08-Jun-93	<i>cis</i> -1,2-Dichloroethene	13
P-16US	P-16US	26-Oct-91	<i>trans</i> -1,2-Dichloroethene	2
P-16US	P-16US	26-Oct-91	<i>cis</i> -1,2-Dichloroethene	290
P-16US	QM-016	13-Mar-91	1,2-Dichloroethene	390
P-16US	WQM021	09-Dec-90	1,2-Dichloroethene	360
P-19US	P-19US1/31/92	31-Jan-92	<i>cis</i> -1,2-Dichloroethene	620
P-19US	P-19US4/28/92	28-Apr-92	<i>cis</i> -1,2-Dichloroethene	680
P-19US	P-19US7/29/92	29-Jul-92	<i>cis</i> -1,2-Dichloroethene	870
P-19US	P-19US1/26/93	26-Jan-93	<i>cis</i> -1,2-Dichloroethene	930
P-19US	P-19US10/09/93	9-Oct-93	<i>cis</i> -1,2-Dichloroethene	940
P-19US	P-19US1/22/94	22-Jan-94	<i>cis</i> -1,2-Dichloroethene	710
P-19US	P-19US7/26/94	26-Jul-94	<i>cis</i> -1,2-Dichloroethene	640
P-22M	P-22M	22-Oct-91	<i>cis</i> -1,2-Dichloroethene	4
P-22M	P-22MIDDLE	27-Jan-90	<i>cis</i> -1,2-Dichloroethene	2
P-22U	P-22UPPER	27-Jan-90	<i>cis</i> -1,2-Dichloroethene	240
P-22U	WQM017	08-Dec-90	1,2-Dichloroethene	150
P-27U	P-27U-01	16-Sep-91	<i>cis</i> -1,2-Dichloroethene	390
P-27U	P-27U-01DL	16-Sep-91	<i>cis</i> -1,2-Dichloroethene	360
P-27U	P27U-11	18-Oct-91	Vinyl Chloride	22
P-27U	P27U-11	18-Oct-91	<i>cis</i> -1,2-Dichloroethene	410
P-27U	P27U-11D	18-Oct-91	<i>cis</i> -1,2-Dichloroethene	420

West of the Assembly Building and Building 14, VOC results indicated that well P-06M contained 11 $\mu\text{g/L}$ *cis*-1,2-DCE and 5 $\mu\text{g/L}$ vinyl chloride in October 1991. Monitoring well P-22U contained 240 $\mu\text{g/L}$ *cis*-1,2-DCE in January 1990 and 150 $\mu\text{g/L}$ total 1,2-DCE in December 1990. The middle Paluxy well P-22M also was found to contain low levels of *cis*-1,2-DCE in October 1991 and January 1990, indicating that the TCE degradation products may be migrating into the middle Paluxy aquifer at this location. *cis*-1,2-DCE was also detected on two occasions at concentrations of 390 and 410 $\mu\text{g/L}$ in well P-27U.

Additional VOCs detected above CRQLs in Paluxy Formation groundwater include 1,2-DCE, methylene chloride, toluene, 2-hexanone, chloroform, and 1,1-DCA. Table 1-102 summarizes the results for these compounds in the Paluxy Formation. Figure II-21 of the RI shows occurrences of these additional VOCs.

Table 1-102. Other VOCs Detected in the Paluxy Formation Groundwater

Well ID	Sample ID	Sample Date	Chemical Name	Result ($\mu\text{g/L}$)	MCL ($\mu\text{g/L}$)
P-09US	NAA215	29-Apr-90	Toluene	800	1,000
P-09US	NAA215	29-Apr-90	2-Hexanone	2,200	—
P-09US	NAA215	29-Apr-90	Methylene Chloride	2,500	5
P-11U	NAA218	30-Apr-90	Methylene Chloride	6	5
P-12M	AFR-005	12-Jun-91	Toluene	2	1,000
P-12M	AFR-005	12-Jun-91	1,1-Dichloroethane	14	5
P-12M	WQM016	08-Dec-90	1,1-Dichloroethane	20	5
P-16US	NAA228	02-May-90	Methylene Chloride	120	5
P-22M	NAA275	01-May-90	Toluene	12	1,000
P-22M	P-22M	22-Oct-91	Toluene	19	1,000
P-22M	WQM015	08-Dec-90	Toluene	7	1,000
P-24M	AFR-008	12-Jun-91	Chloroform	1	100

The highest concentrations of these compounds were identified in the East Parking Lot area in monitoring well P-09US, which contained 800 $\mu\text{g/L}$ toluene, 1,500 $\mu\text{g/L}$ 1,2-DCA, 2,200 $\mu\text{g/L}$ 2-hexanone, and 2,500 $\mu\text{g/L}$ methylene chloride (April 1990 sampling).

These VOC concentrations together with the concentrations of TCE and TCE-degradation products (Tables 1-100 and 1-101) show that P-09US contains the highest levels of organic contamination in the Paluxy Aquifer. As shown in Appendix D of the RI, P-9US also contains the highest water levels of any East Parking Lot well in the Paluxy Formation. These observations reveal that the contamination found in P-09US must originate near the location of this well. The declining trend in TCE concentration at P-09US (Table 1-100) also suggests a local source that has become or is becoming exhausted. As noted earlier, likely sources include vertical migration through the open borehole during construction of the well, or migration along the surface casing due to incomplete sealing of the annular space between the surface casing and the borehole wall.

The trend of increasing TCE concentrations at P-08US and P-15US is likely a reflection of renewed vertical migration of TCE through the eroded section of Walnut Formation limestone in the window area. The apparent recent loss of 20,000 gallons of TCE in Building 181 may have provided the source for this vertical TCE flux via DNAPL migration down the East Parking Lot paleochannel and into the window area.

TCE concentrations between 7,100 $\mu\text{g/L}$ and 11,000 $\mu\text{g/L}$ at P-19US appear as a dramatic increase because no values have been reported for this well prior to the quarterly sampling program performed by Jacobs Engineering Group, Inc. However, the lack of data prior to the quarterly sampling program is due to absence of samples collected from this well. Sampling was not performed previously because the well had only a few inches of water and could not be purged, a requirement for conventional sample collection. Since 1992, water levels have increased, providing three to four feet of water from which to collect a sample after purging a single bore volume (slow recovery precludes purging the standard three bore volumes). Although a sound explanation for the sudden increase in the water level at P-19US is not readily explained in the absence of increasing water levels elsewhere in the upper sand or in the upper zone, several hypothesis exist for the presence of contamination at P-19US. These include:

- a one-time contaminant migration down the open borehole during well installation;
- ongoing contaminant migration along the surface casing due to a defect in the well installation;
- lateral migration of contamination that entered the upper sand in the window area;
- contaminant migration through an undetected zone in the vicinity of P-19US where the Walnut Formation is thin or absent.

Resolution of this uncertainty is expected to be accomplished during remedial design data collection that is scheduled to be performed after completion of the RI/FS.

Low levels of toluene and methylene chloride were detected in monitoring wells P-11U and P-12M, respectively. Monitoring well P-16US contained 120 $\mu\text{g/L}$ methylene chloride. Well P-22M, west of Assembly Building and Building 14, contained low levels of toluene, and well P-24M contained very low levels of chloroform. These wells are within Landfill No. 3.

Although methylene chloride and toluene are common laboratory contaminants (EPA 1988), and 2-hexanone is a common laboratory solvent, results for these occurrences were not qualified, suggesting that a source may exist for these compounds. Methylene chloride may have been used as a solvent at Plant 4. The levels in the Paluxy Formation are quite low with the exception of monitoring well P-09US.

Low levels of 1,1-DCA were present on two occasions above the CRQL in monitoring well P-12M. The organic solvent 1,1,1-TCA degrades to 1,1-DCA through a dehalogenation process and may be a source for the 1,1-DCA. Since the groundwater in the Paluxy Formation flows south in the vicinity of well P-12M, the likely source for the 1,1-DCA would be the 1,1,1-TCA plume located in the upper-zone flow system west of the Assembly Building/Parts Plant. The migration of the 1,1-DCA would occur by vertical flow between the upper-zone flow system and the Paluxy Formation.

In sampling conducted after the completion of the RI field work (Jacobs Engineering Group, Inc. December 1992), no significant changes were found in the distribution or detection of VOCs other than TCE.

Semi-VOCs, TPH, Oil and Grease

This section presents the results of sampling and analyses for semi-VOCs, TPH, and oil and grease in the Paluxy Formation. A summary of the number of samples collected, number of samples exceeding CRQL, and minimum and maximum values is presented in Table 1-103.

Table 1-103. Summary of Analytical Results for Semi-VOCs, TPH, and Oil and Grease in the Paluxy Formation

Chemical Name	Minimum	Maximum	Number of Samples	Number of Samples Exceeding CRQL
Bis(2-ethylhexyl)phthalate	10U $\mu\text{g/L}$	22 $\mu\text{g/L}$	15	4
Total Petroleum Hydrocarbons	0.2 mg/L	0.6 mg/L	17	11
Oil and Grease	0.2 mg/L	2.2 mg/L	18	13

As shown in the table, the only semi-VOCs detected in groundwater of the Paluxy Formation is bis(2-ethylhexyl)phthalate, a common laboratory contaminant. This compound was detected in upgradient monitoring wells, P-29M and P-30M (see Table 1-104). In addition to being a common laboratory contaminant, bis(2-ethylhexyl)phthalate is also a common field contaminant because the plastic (high density polyethylene) used in the manufacture of water jugs dissolves into the distilled water used to rinse sampling equipment.

Table 1-104. Analytical Results for Bis(2-ethylhexyl)phthalate in the Paluxy Formation

Well ID	Sample ID	Sample Date	Result ($\mu\text{g/L}$)
P-29M	P-29M-01	19-Sep-91	11
P-29M	P-29M-11	15-Oct-91	22
P-30M	P-30M-01	16-Sep-91	21

One potential, but unlikely, source of phthalate contamination in P-29M is due to leakage of surface water and upper zone groundwater through the incised bedrock along Meandering Road Creek. However, hydraulic head measurements suggest that P-29M is upgradient from Plant 4. Further, numerical modeling results suggest that the drawdown in White Settlement water supply well

WS-2 will not extend to monitoring well P-29M and, therefore, it is unlikely that the cone of depression in WS-2 could pull contaminants upgradient from the P-29M/Meandering Road Creek location.

For sampling conducted after the completion of the RI field work, semi-VOC analyses were conducted only on a limited basis for Paluxy Formation wells. No semi-VOCs were detected.

Groundwater samples were also collected from the Paluxy Formation for TPH and oil and grease analysis. TPH and oil and grease results are presented in Table 1-105 and posted in Figure II-22 of the RI. The detection limit for both TPH and oil-and-grease measurements was 0.2 mg/L. Monitoring well WS-02 contained 0.2 mg/L oil and grease. The highest concentrations reported were found in wells WS-02 and P-11U. Monitoring well P-11U contained 0.6 mg/L TPH and 0.6 mg/L oil and grease. Monitoring well P-11U was sampled for these components after it was discovered that lubricating oil had leaked from the dedicated pump installed in this well. All other occurrences of oil and grease and TPH were at or near the detection limit.

In sampling conducted after the completion of the RI field work, only the January 1993 sample from P-27U was found to contain oil and grease at 1.2 mg/L. TPH was not detected in any of the post-RI samples that were analyzed for this analyte.

Because only isolated occurrences of oil and grease and TPH were reported in Paluxy Formation groundwater, the low levels detected most likely represent contamination from the dedicated submersible pumps installed in those monitoring wells.

1.5.5.4 Paluxy Formation: Inorganic Contamination

Four monitoring wells completed in the Paluxy Formation during the RI and three wells installed by previous contractors were selected for inorganic analyses (see Appendix F of the RI). Table 1-106 summarizes the results of the 1990-1991 sampling campaigns. The action levels listed in Table 1-106 refer to the EPA drinking water standards. For purposes of comparison, the number of samples that exceed the action level are tabulated.

Figure II-23 of the RI shows analytical results of inorganic priority pollutants for samples collected during the 1990-1991 RI and for samples collected by previous contractors over the 1988-1992 monitoring period. In all cases, the posted values represent the most recent analytical results available.

The data collected during the 1990-1991 monitoring period and presented in Table 1-106 indicate that no priority-pollutant inorganic constituents, except for lead, were detected above drinking water standards in any of the groundwater samples collected from the Paluxy Formation groundwater. Lead was detected in one sample from P-27U at a concentration of 15.1 $\mu\text{g/L}$, a value that is essentially the same as the drinking water standard of 15 $\mu\text{g/L}$ (at the tap). Over the 1988-1991 monitoring period, as shown in Figure II-23 of the RI, lead, zinc, arsenic, copper, nickel, antimony, and silver have been detected in Paluxy Formation groundwater. Antimony and lead are the only analytes that exceed MCLs. Lead was detected at 370 $\mu\text{g/L}$ and antimony at 370 $\mu\text{g/L}$ in monitoring well P-12UN. Antimony was also detected in well P-8UN at 220 $\mu\text{g/L}$.

Table 1-105. Analytical Results for TPH and Oil and Grease in the Paluxy Formation

Chemical Name	Site ID	Sample ID	Sample Date	Result (mg/L)
Oil and Grease	P-05M	P-5M	24-Oct-91	0.2
Total Petroleum Hydrocarbons	P-05M	P-5M	24-Oct-91	0.2
Oil and Grease	P-08M	P-8M	19-Oct-91	0.2
Total Petroleum Hydrocarbons	P-08M	P-8M	19-Oct-91	0.2
Oil and Grease	P-08UN	P-8UN	19-Oct-91	0.3
Total Petroleum Hydrocarbons	P-08UN	P-8UN	19-Oct-91	0.2
Oil and Grease	P-09UN	P-9UN	20-Oct-91	0.2
Total Petroleum Hydrocarbons	P-09UN	P-9UN	20-Oct-91	0.2
Oil and Grease	P-09US	P-9US	20-Oct-91	0.2
Total Petroleum Hydrocarbons	P-09US	P-9US	20-Oct-91	0.2
Oil and Grease	P-10M	P-10M	21-Oct-91	0.2
Total Petroleum Hydrocarbons	P-10M	P-10M	21-Oct-91	0.2
Oil and Grease	P-11M	P-11M	18-Oct-91	0.2
Total Petroleum Hydrocarbons	P-11M	P-11M	18-Oct-91	0.2
Oil and Grease	P-11U	WQM013	08-Dec-90	0.6
Total Petroleum Hydrocarbons	P-11U	WQM013	08-Dec-90	0.6
Oil and Grease	P-12UN	P-12UN	18-Oct-91	0.3
Total Petroleum Hydrocarbons	P-12UN	P-12UN	18-Oct-91	0.2
Oil and Grease	P-15U	P-15U	21-Oct-91	0.2
Total Petroleum Hydrocarbons	P-16US	P-16US	26-Oct-91	0.2
Oil and Grease	P-24M	P-24M	22-Oct-91	0.3
Oil and Grease	WS-02	WS-2	24-Oct-91	2.2
Total Petroleum Hydrocarbons	WS-02	WS-2	24-Oct-91	0.2
Oil and Grease	WS-12	WS-12	24-Oct-91	0.2

During sampling conducted after completion of the RI field work, lead (0.016 mg/L in P-14US, January 1993) was the only priority pollutant metal detected above the MCL.

Aluminum and iron were detected above their respective SMCLs in samples collected during the 1990-1991 sampling period (see Table 1-106). Aluminum was detected in monitoring well P-08US at a concentration of 980 $\mu\text{g/L}$. This well is located in the center of the East Parking Lot Plume, and the elevated value is potentially the result of vertical leakage from the upper-zone flow system. Evidence supporting this position is provided by several monitoring wells located near P-08US that were completed in the upper-zone flow system and exhibited elevated concentrations of aluminum. For example, groundwater collected from the upper-zone well HM-093, located approximately 850 feet northwest of P-08US, was found to contain the highest aluminum concentration (13,500 $\mu\text{g/L}$) measured during the 1990-1991 sampling campaign (see Table 1-97). In the vicinity of well HM-093, Paluxy Formation groundwater flows southeast, toward monitoring well P-08US.

**Table 1-106. Results of Inorganic Analyses for Paluxy Groundwater
Collected During the 1990-1991 Sampling Events**

Chemical Name	Minimum Result (µg/L)	Maximum Result (µg/L)	Action Level (µg/L)	Number of Samples Analyz ed	Number of Samples Above Action Level
Aluminum ^a	980	980	NA	1	NA
Antimony ^b	56U ^c	60U	10	10	0
Arsenic ^d	3U	6.3B	50	10	0
Barium ^d	100U	100U	2,000	1	0
Beryllium ^b	1U	5U	1	10	0
Cadmium ^e	2U	5U	5	10	0
Calcium	75,000	89,100	NA	5	NA
Chromium ^e	5U	32.7	100	14	0
Cobalt	50U	50U	NA	1	NA
Copper ^a	5U	9B	NA	10	NA
Iron ^a	140	512	NA	5	NA
Lead ^b	2U	15.1	15	10	1
Magnesium	1,000U	31,500U	NA	5	NA
Manganese ^a	15U	15U	NA	1	NA
Mercury ^e	0.2U	0.2U	2	1	0
Nickel ^b	22U	55.4	100	10	0
Potassium	4,610B	13,000	NA	5	NA
Selenium ^e	3U	30U	50	10	0
Silver ^a	4U	10U	NA	10	NA
Sodium	25,200	31,000	NA	5	NA
Thallium ^b	2U	2B ^f	2	10	0
Vanadium	50U	50U	NA	1	NA
Zinc ^a	8B	83.6	NA	10	NA

^a No action level exists for this chemical because it is regulated by secondary standards.

^b Action level for this chemical is the Maximum Contaminant Level (MCL) (FR V.57 No. 138).

^c U indicates the chemical was not detected.

^d Action level for this chemical is the MCL (40 CFR 141.11).

^e Action level for this chemical is the MCL (FR. V.56 No. 20).

^f Action level for this chemical is the MCL (FR. V.56 No. 110).

^g B indicates the result is above or equal to the IDL but less than the Contract RDL.

Iron was also detected above the SMCL during the 1990-1991 sampling events, at concentrations ranging from 447 to 512 $\mu\text{g/L}$ (well P-29). However, these values are not considered to be elevated above natural concentrations but rather are typical of water quality found in the Paluxy Formation (Nordstrom 1983).

1.5.6 Surface Water Contamination

This section discusses the occurrences of contamination identified in surface waters located adjacent to Plant 4, including Meandering Road Creek, Lake Worth, and Farmers Branch. These features were selected for the investigation based on the current hydrogeologic model for the site. The model suggests that interactions between groundwater and surface water systems may have resulted in contaminants being transported to these surface waters.

Surface water sampling locations along Meandering Road Creek and Lake Worth are shown in Figure 1-62. The sampling site established on Farmers Branch is located near the outlet of the aqueduct that conveys water under the runway at CAFB.

Analytical results for surface water samples collected between February 1990 and October 1991 are presented in Appendix F-1 of the RI. Assessments of the nature and extent of contamination identified in Lake Worth, Meandering Road Creek, and Farmers Branch are discussed separately below.

1.5.6.1 Meandering Road Creek

Surface water samples collected along Meandering Road Creek included 40 samples collected directly from the creek and three samples collected from a seep located on the east margin of the stream near the boundary of Landfill No. 3 (see Figure 1-62). Although the quality of water originating at the seep is more indicative of local groundwater quality, analytical results for samples obtained at the seep are included in this section because water from the seep is tributary to the stream.

Volatile Organic Compounds

VOCs detected in surface water samples collected along Meandering Road Creek are listed in Table 1-107. TCE and *cis*-1,2-DCE were the most frequently detected VOCs during the sampling period. Concentrations of TCE ranged from 8 $\mu\text{g/L}$ at sample site Creek Seep to 140 $\mu\text{g/L}$ at site ST-5, the storm sewer outfall. *cis*-1,2-DCE was detected at concentrations ranging from 6 $\mu\text{g/L}$ at site SW-07 to 430 $\mu\text{g/L}$ at site SW-08. The VOCs detected at concentrations exceeding MCLs included TCE, vinyl chloride, *cis*-1,2-DCE, and 1,2-DCA.

Concentrations of VOCs detected in surface water samples collected along Meandering Road Creek are presented in Table 1-108. VOC concentrations above MCLs were reported at sample sites C-4 (TCE), Creek Seep (TCE), SS-01 (1,2-DCA, vinyl chloride, TCE, and 1,2-DCE), SW-08 (*cis*-1,2-DCE, vinyl chloride), and ST5 (TCE). The highest VOC concentrations were detected in samples collected at sites SS-01, SW-08, and ST5. These three sites are located along the reach of Meandering Road Creek that borders the central portion of Landfill No. 3.

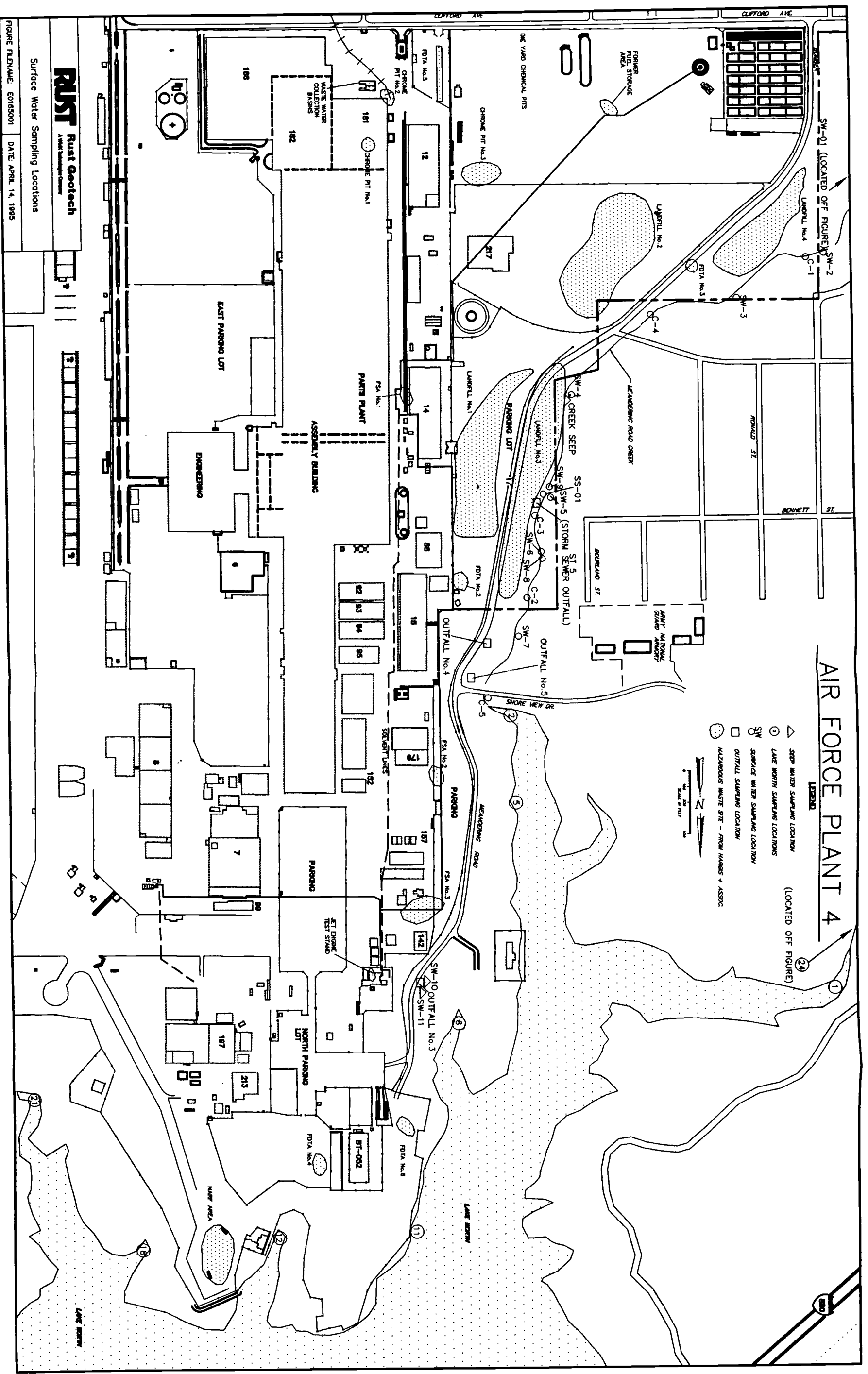


Figure 1-62. Surface Water Sampling Locations Along Meandering Road Creek and Lake Worth.

**Table 1-107. VOCs Detected in Surface Water Samples Collected Along
Meandering Road Creek Between February 1990 and October 1991**

Chemical Name	Minimum Concentration Detected $\mu\text{g/L}$	Maximum Concentration Detected $\mu\text{g/L}$	No. of Samples Analyzed	No. of Samples Above CRQL	No. of Samples Above MCL
Trichloroethene	8	140	41	7	7
2-Butanone	12	16	41	4	-
Methylene Chloride	1	1	43	1	0
Vinyl Chloride	14	120	43	3	3
Acetone	12	13	41	2	-
1,2-Dichloroethene	41	1,800	27	2	-
<i>trans</i> -1,2-Dichloroethene	3	3	16	1	0
<i>cis</i> -1,2-Dichloroethene	6	430	16	9	3
Chlorobenzene	1	1	43	1	0
1,2-Dichloroethane	14	14	41	1	1

A comparison of surface water results (see Table 1-108) and surface water sampling locations along Meandering Road Creek (see Figure 1-62) indicates that VOC contamination is entering the creek in the vicinity of Plant 4. Acetone, at a concentration of 12 $\mu\text{g/L}$, was the only VOC found upstream of the site. It was detected in the sample collected at SW-01, which is located approximately 1,000 feet upstream from the Plant 4 boundary. As the stream approaches Plant 4, the first VOC reported was TCE, which was detected at a concentration of 14 $\mu\text{g/L}$ in a sample collected directly from the creek at sample site C-4. As stated above, the highest VOC concentrations were reported along the reach of Meandering Road Creek that borders Landfill No. 3. Along this portion of the creek, VOCs were detected in samples collected directly from the creek (sites SS-01 and SW-08), the storm sewer outfall (site ST5), and the seep (site Creek Seep). The lower levels of VOC contamination detected in samples collected downstream of Landfill No. 3 are likely a combined result of dilution, volatilization, and less contamination entering the creek downstream of the landfill. Contaminated upper-zone groundwater is the most likely source for VOC contamination in Meandering Road Creek.

Semivolatile Organic Compounds

The only semi-VOCs detected in surface water samples collected along Meandering Road Creek were 4-methylphenol and 1,2-dichlorobenzene. 4-methylphenol was detected at one sample site, SS-01, at a concentration of 14 $\mu\text{g/L}$. 1,2-dichlorobenzene was detected at one sample site, SW-08, at a concentration of 3 $\mu\text{g/L}$. Samples SS-01 and SW-08 were collected directly from the stream adjacent to Landfill No. 3. Discharge of contaminated upper-zone groundwater into Meandering Road Creek near Landfill No. 3 is a potential source for this contamination.

Table 1-108. Concentrations of VOCs Detected in Surface Water Along Meandering Road Creek Between February 1990 and October 1991

Sample Site	Sample Date	Concentration $\mu\text{g/L}$	Chemical Name
C-1	28-Feb-90	16	2-Butanone
C-2	28-Feb-90	14	2-Butanone
C-4	28-Feb-90	13	2-Butanone
C-4	30-Apr-90	14	Trichloroethene
C-5	28-Feb-90	12	2-Butanone
Creek Seep	28-Feb-90	8	Trichloroethene
Creek Seep	28-Mar-90	9	Trichloroethene
Creek Seep	30-Apr-90	12	Trichloroethene
SS-01	01-Mar-91	14	1,2-Dichloroethane
SS-01	01-Mar-91	41	1,2-Dichloroethene
SS-01	01-Mar-91	120	Vinyl Chloride
SS-01	01-Mar-91	13	Trichloroethene
SS-01	01-Mar-91	1,800	1,2-Dichloroethene
SW-01	02-May-91	12	Acetone
SW-03	02-May-91	13	Acetone
SW-05	22-Oct-91	1	Methylene Chloride
SW-05	01-May-91	21	<i>cis</i> -1,2-Dichloroethene
SW-05	01-May-91	40	<i>cis</i> -1,2-Dichloroethene
SW-05	02-May-91	57	<i>cis</i> -1,2-Dichloroethene
SW-06	01-May-91	42	<i>cis</i> -1,2-Dichloroethene
SW-07	01-May-91	6	<i>cis</i> -1,2-Dichloroethene
SW-08	22-Oct-91	1	Chlorobenzene
SW-08	22-Oct-91	150	<i>cis</i> -1,2-Dichloroethene
SW-08	22-Oct-91	3	<i>trans</i> -1,2-Dichloroethene
SW-08	22-Oct-91	17	Vinyl Chloride
SW-08	02-May-91	500E	<i>cis</i> -1,2-Dichloroethene
SW-08	02-May-91	14	Vinyl Chloride
SW-08	02-May-91	430	<i>cis</i> -1,2-Dichloroethene
SW-09	02-May-91	33	<i>cis</i> -1,2-Dichloroethene
ST5	28-Mar-90	140	Trichloroethene
ST5	30-Apr-90	25	Trichloroethene

TPH and Oil and Grease

TPH were detected in three of 11 samples analyzed for TPH. Two of the samples containing detectable concentrations of TPH were collected directly from the creek at sites SW-01 and SW-02 located upstream of Plant 4. TPH concentrations reported for samples SW-01 and SW-02 were 1 and 2 mg/L, respectively. Potential sources for this contamination are unknown but are not considered to

be associated with Plant 4 operations. The third sample in which TPH were detected was collected at site SW-08, located near Landfill No. 3. The TPH concentration reported for SW-08 was at the method reporting limit, 0.2 mg/L. TPH were not detected in other samples collected along the portion of Meandering Road Creek that is adjacent to Plant 4.

Oil and grease were detected in ten of 28 samples analyzed for oil and grease. Samples collected in May 1991 at sites SW-01 and SW-02, located upstream of Plant 4, contained oil and grease at concentrations of 2 and 3 mg/L, respectively. Sample sites located adjacent to Plant 4 and at which oil and grease were detected include C-2 (6, 10, and 16 mg/L), C-3 (6 mg/L), C-4 (10 mg/L), C-5 (10 mg/L), SW-06 (0.5 mg/L), and SW-08 (0.2 mg/L).

Samples were collected for oil and grease analysis at C-2, C-3, C-4, and C-5 in February, March, and April 1990. Oil and grease were detected at each of these sample sites only during the March 1990 sampling event. During the subsequent sampling event, oil and grease were detected only at sample site C-2. Oil and grease results at these sample sites suggest that oil and grease contamination may be a transitory condition in the reach of Meandering Road Creek that borders Plant 4. The most likely pathway for oil and grease to be discharged to the stream in the vicinity of Plant 4 is the storm sewer outfall. Oil and grease concentrations at SW-06 and SW-08 were reported in samples collected in May and October 1991, respectively. No subsequent sampling events have been performed to confirm the low levels of oil and grease contamination identified at these sample sites.

Metals

The analytes included in metals analyses were antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, and zinc. A summary of metals results in surface water samples collected along Meandering Road Creek is presented in Table 1-109. As shown, the only metals detected were zinc, lead, and chromium. All metal concentrations were reported at values below SMCLs (zinc) and MCLs (lead and chromium). Zinc was reported at concentrations above the method detection limit in each of the eight samples submitted for metals analysis. Lead and chromium were detected in one and three samples, respectively.

Concentrations of metals detected in surface water samples collected along Meandering Road Creek are listed in Table 1-110. Zinc concentrations of 22.6 and 49.6 $\mu\text{g/L}$ were detected upstream of Plant 4 at sample sites SW-01 and SW-02, respectively. Zinc concentrations in samples collected from the stream near Plant 4 ranged from 24.2 $\mu\text{g/L}$ at SW-04 to 60.5 $\mu\text{g/L}$ at SW-06. These results suggest that surface water runoff and groundwater discharge to Meandering Road Creek in the vicinity of Plant 4 do not significantly impact zinc concentrations in the stream.

The remaining metals listed in Table 1-109 were detected at SW-04, located near Landfill No. 3. Chromium was detected at SW-04 during two separate sampling events at concentrations ranging from 12.8 to 15.8 $\mu\text{g/L}$. Lead was detected at SW-04 during one sampling event at a concentration of 6.7 $\mu\text{g/L}$. Contaminated upper-zone groundwater is the suspected source for this contamination.

Table 1-109. Summary of Metals Analytical Results for Surface Water Samples Collected Along Meandering Road Creek

Analyte	Minimum Concentration Detected µg/L	Maximum Concentration Detected µg/L	Maximum Contaminant Level (MCL) µg/L	No. of Samples Analyzed	No. of Samples Above Detection Limit
Antimony	ND ^a	ND	6	8	0
Arsenic	ND	ND	50	8	0
Beryllium	ND	ND	4	8	0
Cadmium	ND	ND	5	8	0
Chromium	12.7	15.8	100	8	3
Copper	ND	ND	1,300 ^b	8	0
Lead	6.7	6.7	15	8	1
Nickel	ND	ND	100	8	0
Selenium	ND	ND	50	8	0
Silver	ND	ND	100 ^b	8	0
Thallium	ND	ND	2	8	0
Zinc	22.6	60.5	5,000 ^b	8	8

Notes: ^aND = not detected
 ^b = secondary standard

Table 1-110. Concentrations of Metals Detected in Surface Water Samples Collected Along Meandering Road Creek

Sample Site	Sample Date	Concentration µg/L	Analyte
SW-01	02-May-91	22.6	Zinc
SW-02	02-May-91	49.6	Zinc
SW-03	02-May-91	35.6	Zinc
SW-04	01-May-91	12.7	Chromium
SW-04	01-May-91	39.0	Zinc
SW-04	01-May-91	15.8	Chromium
SW-04	01-May-91	41.2	Zinc
SW-04	02-Jul-91	12.8	Chromium
SW-04	02-Jul-91	6.7	Lead
SW-04	02-Jul-91	24.2	Zinc
SW-06	01-May-91	60.5	Zinc
SW-07	01-May-91	30.5	Zinc

1.5.6.2 Lake Worth

A total of nine surface water samples were collected from Lake Worth in October 1991. Lake Worth sampling locations are shown in Figure 1-62. Seven of the sample sites (LW-02, LW-05, LW-08, LW-11, LW-12, LW-18, and LW-21) were located along the northern boundary of Plant 4. Samples at the remaining two sites, LW-01 and LW-24, were obtained to assess background conditions. One of the background samples was collected west of the site and north of the community of White Settlement. The second background sample was taken from a tributary draining into the lake.

Lake Worth samples were submitted for VOC, semi-VOC, TPH, oil and grease, and metals analysis. In addition, samples collected at sites LW-01, LW-02, and LW-24 were also submitted for pesticide analysis. Carbon disulfide and oil and grease were the only analytes detected above method reporting limits. No semi-VOCs, metals, or pesticides were detected in samples collected from Lake Worth.

Carbon disulfide was reported at concentrations of 200, 18, and 160 $\mu\text{g/L}$ at sites LW-05, LW-12, and LW-18, respectively. All of these sites are located along the north boundary of Plant 4. The distribution of carbon disulfide results implies that the contamination did not originate from a common source. Although potential sources have not been identified, the relatively high concentrations reported suggest that the sources are likely to be near the points of sample collection.

Oil and grease were reported at a concentration of 2.01 mg/L at the background sampling location LW-01. The source for this low-level contamination is unknown.

In addition to samples taken directly from the lake, samples were also collected from Outfall No. 3 and seeps SW-10 and SW-11, located upslope of Lake Worth near the northwestern boundary of Plant 4 (see Figure 1-62). Samples from Outfall No. 3 and SW-10 were analyzed for VOCs, semi-VOCs, TPH, oil and grease, and metals. Samples from SW-11 were analyzed for TPH and oil and grease. No target analytes were detected in samples from Outfall No. 3 or SW-11. However, concentrations of zinc (44.2 $\mu\text{g/L}$), arsenic (11.2 $\mu\text{g/L}$), and silver (133 $\mu\text{g/L}$) were reported in the seep sample collected at SW-10. The concentrations reported for zinc and arsenic were confirmed in duplicate sample analyses. The high silver concentration reported for SW-10, which exceeds the secondary standard established for silver, was not confirmed in the duplicate sample. Contaminated upper-zone groundwater is the most likely source for the metals contamination reported at SW-10.

1.5.6.3 Farmers Branch

Farmers Branch Creek is a small stream that flows easterly along the southern portion of the plant and CAFB. Immediately upon entering the CAFB boundary just east of Grants Lane, it flows through an aqueduct under the runway and taxiway, resurfacing near the Carswell Air Force Base golf course. It then flows through the golf course and empties directly into the West Fork of the Trinity River.

Up to five locations have been sampled in the Farmers Branch drainage during the quarterly groundwater sampling performed by Jacobs Engineering Group from 1992 to the present (see Plate 2). The farthest upstream location (EGL-1) is at the mouth of the aqueduct as the creek enters CAFB property. The farthest downstream location (LF05-S6) is in the golf course area, east of Carswell Landfills 4 and 5.

Organic contaminants measured in Farmers Branch Creek include trichloroethene (TCE), and *cis*- and *trans*-1,2-dichloroethene. Vinyl chloride has not been detected. Concentrations are lowest at location EGL-1 with values at or near detection limits. As the creek flows through the aqueduct, shallow groundwater recharges the creek as indicated by elevated TCE concentrations at EGL-2. The highest values have been measured in an unnamed tributary southeast of CAFB Landfills 4 and 5 (sample location LF05-S7). In 1992 TCE was measured at 880 µg/L at this location. Since 1992, concentrations of TCE have varied between 100 and 500 µg/L. The most recent TCE value measured is 100 µg/L (February 1995). The highest value of TCE measured in the creek is 67 µg/L, measured in March 1994 at a location downstream of the unnamed tributary (LF05-S6). The apparent trend of decreasing concentrations in the Farmers Branch drainage may be associated with contaminant removal by the Landfill 4 and 5 pump and treat system.

Cis-1,2-dichloroethene (*cis*-DCE) values follow TCE values, the highest being 380 µg/L at location LF05-S7 in the unnamed tributary. The highest *cis*-DCE value measured in the creek is 29 µg/L measured at LF05-S6.

Concentrations of inorganic compounds are at or near levels measured at SW-01, a location considered unaffected by Plant 4 activities.

1.5.7 Ecological Contamination

1.5.7.1 Toxicity Testing

Surface water samples were collected for toxicity tests from three locations: One on Meandering Road Creek 100 to 200 feet downstream of Landfill No. 4 (Lake Worth Sampling Location 25); one on Meandering Road Creek upstream of Plant 4 (Location 27); and a background location on Live Oak Creek (Location 28). These locations were selected to provide a worst-case sample, a local background sample, and a control sample, respectively. Appendix H-3 of the RI includes a discussion of the tests performed and results. Tests were performed by TRAC Laboratories, Inc. Table 1-111 summarizes the toxicity test results.

Water samples from Location 27 had some toxic effect on *Pimephales promelas* (fathead minnow) in that the mortality rate increased notably over that of the control sample. This may suggest that some toxicity exists in Meandering Road Creek upstream of Plant 4.

Samples from Location 25 had no significant toxic effects at 50 percent exposure but proved toxic to both *Ceriodaphnia dubia* (water flea) and *P. promelas* at 100 percent exposure. At 100 percent exposure, the mean neonate production in *C. dubia* was notably lower than the mean neonate production of the control sample, and there was a significant increase in the mortality rate of *P. promelas*. These findings may suggest that the toxicity of Meandering Road Creek increases as it flows through the Plant 4 area.

Samples from background Location 28 showed no toxic effects on either *C. dubia* or *P. promelas*.

Table 1-111. Results of Toxicity Tests on Samples
(from TRAC Laboratories, Inc. 1991)

Sample ID	Concentration (%)	<i>Ceriodaphnia dubia</i>		<i>Pimephales promelas</i>	
		S ^a n = 10	R ^b	S n = 40	W ^c
Location 25	100	90	23.4 ^d (34) ^f	70 ^d (16)	NC ^e
	50	90	24.9 (36)	95 (6)	0.34 (8)
Location 27	100	90	26.7 (30)	73 ^d (21)	NC
Location 28	100	100	26.9 (20)	83 (12)	0.27 (21)
Control	NA ^e	100	29.4 (16)	95 (6)	0.31 (5)

^aS = % survival

^bR = mean neonate production per female

^cW = mean final dry weight (mg) per fish

^d = significantly different from the control (P < 0.05)

^f = Values in parentheses are % coefficient variation

^eNA = not applicable

^eNC = value not calculated to significant lethal effects

1.5.7.2 Fish Tissue Contamination

Fish tissue samples were collected from five locations, two of which, Location 1 and Location 28, were background locations. Locations 2, 25, and 26 were sited at the west boundary of Plant 4, along Meandering Road Creek. Mosquito fish specimens were collected for tissue analysis; samples were submitted to the Mississippi State Chemical Laboratory (MSCL), where they were composited into five samples for whole-tissue analysis. Constituents of interest were those agreed upon by USFWS and EPA representatives prior to sample collection. These constituents included organochlorines/ PCBs, PAHs, and five metals—aluminum, cadmium, chromium, lead, and nickel. Table 1-112 is a summary of the results of tissue analyses; only those constituents that were detected in any of the five tissue samples are listed. Appendix H of the RI provides a summary of the tissue analyses.

Organochlorines/PCBs were investigated in three of the five tissue samples—those from Locations 28 (background), 25, and 2. Arochlor 1254 and Arochlor 1260 were detected in both on-site tissue samples but not in the background sample. The dichlorodiphenyltrichloroethane (DDT) degradation product p,p'-dichlorodiphenyldichloroethylene (DDE) was measured at the lower level of detection in all three samples, while the degradation product p,p'-dichlorodiphenyldichloroethane (DDD) was measured at the lower level of detection only in the background sample. Dieldrin was measured at the lower level of detection only in the on-site sample from Location 25.

All five tissue samples were investigated for PAHs. Naphthalene was measured at the lower level of detection in the samples from background Locations 1 and 28 and at a slightly greater concentration in the sample from on-site Location 25. Phenanthrene was detected only in the sample from on-site

Location 25. Chrysene was found at the lower level of detection in the sample from background Location 1. Benzo(b)fluoranthene was found at the lower level of detection in the sample from on-site Location 2. No PAH compounds were detected in the sample from on-site Location 26.

Investigations for inorganic compounds included five metals—cadmium, chromium, lead, aluminum, and nickel. Table 1-112 shows that, for the most part, levels of cadmium, lead, and nickel were consistent over all samples, while levels of chromium and aluminum were distinctively higher in the samples from background Locations 1 and 28.

Table 1-112. Summary of the Results of MSCL's Fish Tissue Analyses

Organochlorines/PCBs (ppm-as received wet weight)	Location 1 (Background)	Location 28 (Background)	Location 25	Location 2	Location 26
Arochlor 1254	NA ^a	ND ^b	0.32	0.16	NA
Arochlor 1260	NA	ND	0.09	0.09	NA
p,p'-DDE	NA	0.01	0.01	0.01	NA
Dieldrin	NA	ND	0.01	ND	NA
p,p'-DDD	NA	0.01	ND	ND	NA
PAHs (ppm-as received wet weight)					
Napthalene	0.01	0.01	0.02	ND	ND
Phenanthrene	ND	ND	0.03	ND	ND
Chrysene	0.01	ND	ND	ND	ND
Benzo(b)fluoranthene	ND	ND	ND	0.01	ND
Metals (mg/kg)					
Cadmium	0.17	0.08	0.16	0.12	0.08
Chromium	0.34	0.76	0.32	0.16	0.12
Lead	2.0	2.0	2.0	1.4	2.0
Aluminum	104	96.8	20.4	1.6	27.6
Nickel	1.6	1.6	1.2	0.60	0.76

^aND = Not detected

^bNA = Not analyzed

Lower level of detection = 0.01 ppm, except 0.05 ppm for PCBs

Levels of Arochlor 1254, Arochlor 1260, Dieldrin, naphthalene, phenanthrene, and benzo(b)fluoranthene in on-site tissue samples were elevated compared with background levels of these organic compounds, which may indicate that Plant 4 contributes to the contamination of the aquatic community of Lake Worth. However, the tissue data cannot be considered conclusive for several reasons. At the time of sample collection, Lake Worth was in flood stage and temperatures were unseasonably cool. Mosquito fish tend to occupy territorial areas in warm weather conditions; flood conditions may have displaced the populations that inhabited the sampling locations throughout the summer and introduced new, unrepresentative populations. In addition, the mosquito fish collected may not have inhabited the area long enough to allow toxic compounds to accumulate in

their fatty tissues. Finally, the selection of background sampling locations may have ignored nearby industry, which may have minimized the contrast between background contaminant levels and on-site contaminant levels.

1.5.8 Air Contamination

1.5.8.1 Introduction

Two air monitoring stations were established to provide information on the general air quality for the White Settlement area and to assess the contribution of air contaminants from Plant 4. The air monitoring station established to monitor the offsite concentrations of contaminants was set up inside the security fence at White Settlement municipal well WS-6T, approximately 0.75 mile west of Plant 4. The air monitoring station established to monitor the onsite concentrations of contaminants, and the contribution made from the operations at Plant 4, was set up inside Plant 4 approximately 300 feet north of Building 176. Each station was equipped to collect samples for VOCs, total particulates, and select metals. Sampling was initiated in mid-February 1992 and continued through mid-May 1992. A total of 15 sampling sets were collected during this time period on a six-day rotation. Appendix I-1 of the RI provides the analytical data reports.

In addition to the collection of air-quality monitoring data, daily wind speed and wind direction data were obtained from the meteorological station at CAFB for the period in which the air monitoring was conducted. Table 1-113 summarizes the hourly wind data collected on the days that each air-quality sampling period was initiated. Appendix I-2 of the RI contains a summary of the meteorological data obtained from CAFB.

1.5.8.2 Field and Laboratory Quality Control

Samples for VOC analysis were collected using evacuated SUMMA® passivated stainless steel canisters, and consequently, no trip blanks were required because any positive analytical result from a trip blank canister would indicate only that the individual canister leaked/lost its vacuum, and that result would be canister specific.

Samples for total particulates and metals analyses were collected using Whatman EPM-2000 ultrahigh purity glass fiber filters originating from the same batch. After collection, each filter was placed in a sealed envelope and stored in a secure location so that chain of custody could be maintained until the samples could be batched for efficient analysis. Two blank filters were analyzed for total particulates, cadmium, chromium, lead, and zinc to provide data on the inherent metals content of the filters themselves. The analytical values (measured in $\mu\text{g}/\text{filter}$) for these parameters were as follows: cadmium—0.41 and <0.24; chromium—7.3 and 3.6; lead—2.0 and 1.9; zinc—75.3 and 67. The metals data in Table 1-114 presents total concentrations and also modified data to reflect the averages of these inherent contaminant concentrations.

Laboratory quality controls, in the form of "Standard Reference Solutions" for metals analysis and "Method Blanks" and "Surrogate Recoveries" for VOC analysis, were quantified for each set of samples analyzed. Appendix I-1 of the RI provides the actual values and individual quality control discussions.

**Table 1-113. Summary of Carswell Air Force Base Wind Direction
and Speed Data**

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TIME	FEB 11		FEB 18		FEB 24		MAR 01		MAR 07		MAR 13		MAR 19		MAR 25	
	DIR ¹	SPEED ²	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED
0055	160	4	220	5	100	3	80	1	0	0	30	7	360	6	40	14
0155	140	4	220	6	10	3	0	0	0	0	50	2	350	8	40	20
0255	100	3	210	8	0	0	0	0	0	0	70	2	350	16	80	12
0355	130	2	210	9	0	0	0	0	0	0	60	1	0	0	100	10
0455	130	2	220	9	0	0	170	1	190	4	60	5	350	4	120	10
0555	120	3	230	10	0	0	0	0	0	0	50	2	360	10	130	2
0655	150	10	290	4	0	0	0	0	280	2	70	1	360	7	0	0
0755	160	8	300	5	0	0	0	0	0	0	0	0	310	6	0	0
0855	170	9	0	0	0	0	0	0	280	2	0	0	340	12	270	2
0955	160	8	0	0	340	4	0	0	0	0	0	0	350	15	330	4
1055	160	3	0	0	340	4	0	0	0	0	0	0	350	12	10	2
1155	160	8	0	0	350	5	0	0	0	0	0	0	330	13	330	3
1255	150	8	0	0	350	2	0	0	0	0	0	0	330	10	330	3
1355	150	11	0	0	10	4	0	0	0	0	0	0	330	18	330	2
1455	150	9	330	3	40	6	0	0	0	0	160	8	340	18	330	4
1555	170	7	330	2	10	6	180	2	0	0	150	8	360	18	330	6
1655	170	9	340	6	30	10	230	8	0	0	170	12	350	18	350	4
1755	170	5	350	14	40	8	230	8	180	8	170	10	360	13	20	10
1855	180	10	310	13	10	12	190	8	200	12	200	10	360	14	20	8
1955	170	13	310	12	10	10	190	8	160	12	170	9	350	14	30	8
2055	180	14	350	12	10	14	170	12	170	11	160	3	350	7	10	6
2155	180	10	340	9	340	13	170	14	150	10	170	4	340	6	10	4
2255	170	16	340	9	350	14	170	14	160	12	160	10	340	6	10	6
2355	160	10	340	6	360	13	180	12	150	11	160	8	340	7	0	0
0055	150	14	310	2	10	11	160	10	160	8	160	6	350	6	0	0

¹ Wind direction is measured in degrees (clockwise from the north), and indicates the direction from which the wind is blowing. A zero (0) indicates calm conditions.

² Wind speed is measured in knots.

FREQUENCY TABLE (The numbers indicate the number of hourly readings during each period where the indicated wind direction was observed.)																
Wind direction	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day
CALM	0	11	6	23	7	24	13	14	13	29	7	23	1	10	4	17
S ± 20	15	35	0	47	0	1	9	71	8	22	10	46	0	18	0	37
N ± 20	0	29	6	9	14	54	0	1	0	24	0	5	20	47	8	13
E ± 20	1	6	0	4	1	1	0	4	0	2	2	18	0	6	2	9
W ± 20	0	6	1	4	0	12	0	0	2	5	0	1	1	3	1	3
S ± 40	21	47	5	64	0	2	9	93	10	35	11	56	0	30	0	56
N ± 40	0	33	8	13	17	73	0	1	0	36	1	7	23	57	16	24
E ± 40	4	14	0	10	1	1	1	9	0	10	6	27	0	18	4	18
W ± 40	0	15	6	10	0	20	2	3	2	10	0	7	1	5	1	5
	25	120	25	120	25	120	25	120	25	120	25	120	25	120	25	120

Table 1-113. (continued) Summary of Carswell Air Force Base Wind Direction and Speed Data

TIME	MAR 31			APR 06			APR 12			APR 18			APR 24			APR 30			MAY 06			MAY 12		
	DIR ¹	SPEED ²		DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED	
0055	350	5		70	8		150	10		130	4		160	6		50	6		90	1		210	10	
0155	10	3		80	5		140	7		140	6		150	6		0	0		0	0		210	10	
0255	0	0		120	10		140	8		0	0		150	7		0	0		40	8		220	12	
0355	0	0		90	5		130	8		0	0		160	8		0	0		40	4		0	0	
0455	0	0		150	4		130	8		80	3		160	12		0	0		30	6		0	0	
0555	0	0		20	2		120	8		180	2		170	12		0	0		40	4		130	3	
0655	0	0		80	5		110	9		0	0		150	7		170	2		40	10		130	6	
0755	0	0		90	4		130	9		120	6		140	8		170	2		40	10		130	6	
0855	0	0		80	5		140	13		120	3		140	6		0	0		40	8		140	6	
0955	0	0		70	2		160	8		160	2		140	6		0	0		30	10		160	6	
1055	200	1		70	4		110	4		140	4		140	2		0	0		20	8		140	6	
1155	0	0		60	2		110	4		150	4		140	2		0	0		30	10		150	4	
1255	0	0		50	3		100	4		160	10		330	3		0	0		30	8		150	8	
1355	140	2		50	2		100	4		180	11		230	2		80	2		40	7		170	6	
1455	110	3		70	1		120	6		170	12		230	2		150	3		50	11		180	8	
1555	170	4		10	6		80	4		170	10		230	4		130	5		90	8		190	8	
1655	180	3		350	3		80	4		150	15		350	6		130	5		10	8		240	6	
1755	60	3		330	3		20	8		180	18		340	10		120	4		50	8		180	8	
1855	340	1		330	4		30	8		160	16		10	7		150	9		60	6		140	8	
1955	30	2		310	3		50	4		150	16		10	8		110	9		50	5		100	8	
2055	40	5		360	8		340	8		160	14		10	10		110	11		40	9		70	10	
2155	40	5		10	7		330	10		170	16		10	13		110	11		50	6		40	6	
2255	90	4		20	4		320	13		160	16		10	12		120	9		50	6		60	5	
2355	40	6		0	0		340	15		160	14		10	10		140	10		30	7		90	9	
0055	50	4		60	3		330	15		150	12		20	10		130	11		40	5		130	11	

¹ Wind direction is measured in degrees (clockwise from the north), and indicates the direction from which the wind is blowing. A zero (0) indicates calm

² Wind speed is measured in knots.

FREQUENCY TABLE

(The numbers indicate the number of hourly readings during each period where the indicated wind direction was observed.)

Wind direction	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day	1-day	5-day
CALM	10	29	1	10	0	2	3	24	0	20	10	18	1	12	2	22						
S ±20	3	23	0	59	1	84	12	31	4	11	2	43	0	58	5	23						
N ±20	3	31	6	6	2	21	0	14	9	39	0	12	2	1	0	0						
E ±20	2	5	9	18	7	7	1	6	0	7	4	10	2	3	3	19						
W ±20	0	15	0	0	0	0	0	12	0	0	0	0	0	0	0	0						
S ±40	4	29	1	72	5	73	18	43	12	23	5	50	0	77	13	46						
N ±40	7	37	8	8	7	26	0	25	10	47	0	29	16	16	1	2						
E ±40	4	7	14	29	13	18	4	10	0	27	10	21	8	14	8	47						
W ±40	0	18	1	1	0	1	0	18	3	3	0	2	0	1	1	3						
	25	120	25	120	25	120	25	120	25	120	25	120	25	120	25	120						

Table 1-114. Summary of Inorganic Contaminants in Air Samples

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SAMPLE DATE INORGANIC CONTAMINANT	FEB 11		FEB 18		FEB 24		MAR 01		MAR 07		MAR 13		MAR 19		MAR 25	
	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS
Sample Volume (m ³)	1631	1631	8291	8291	8155	8155	8153	8153	8394	7973	8767	8155	7951	7951	10360	8359
Total Particulates (µg/m ³)	13.0	12.0	18.0	16.0	8.8	8.7	10.0	10.0	13.0	17.0	18.0	20.0	13.0	15.0	13.0	18.0
Total Cadmium Concentration (µg/m ³)	0.0063	0.0037	0.0030	0.0031	0.0021	0.0020	0.0023	0.0020	0.0020	0.0030	0.0030	0.0020	0.0020	0.0020	0.0020	0.0020
Total Chromium Concentration (µg/m ³)	0.86443	0.60347	2.4873	2.57021	1.71255	1.631	1.87619	1.6306	1.6788	2.3918	2.6301	1.631	1.5902	1.5902	2.072	1.8718
Net Cadmium Concentration (µg/m ³)	0.58943	0.33847	2.2223	2.30521	1.44755	1.368	1.61019	1.3656	1.4138	2.1268	2.3851	1.368	1.3252	1.3252	1.807	1.4088
Net Chromium Concentration (µg/m ³)	0.0037	0.0021	0.0027	0.0028	0.0018	0.0017	0.0020	0.0017	0.0017	0.0027	0.0027	0.0017	0.0017	0.0017	0.0017	0.0017
Total Lead Concentration (µg/m ³)	0.0055	0.0074	0.0019	0.0081	0.0086	0.0080	0.0022	0.0088	0.0023	0.0011	0.0082	0.0010	0.0012	0.0009	0.0027	0.0007
Total Chromium (µg)	8.9705	12.0694	15.7529	67.1571	70.133	85.24	17.8368	71.7464	19.3062	8.7703	54.3554	8.155	8.5412	7.1559	27.972	5.8513
Net Chromium (µg)	3.5205	6.6184	10.3029	61.7071	64.683	59.79	12.4866	66.2964	13.8562	3.3203	48.9054	2.705	4.0912	1.7059	22.522	0.4013
Net Chromium Concentration (µg/m ³)	0.0022	0.0041	0.0012	0.0074	0.0079	0.0073	0.0015	0.0081	0.0017	0.0004	0.0056	0.0003	0.0005	0.0002	0.0022	0.0000
Total Lead Concentration (µg/m ³)	0.0059	0.0086	0.0048	0.0039	0.0032	0.0032	0.0038	0.0042	0.0043	0.0044	0.0087	0.0055	0.0067	0.0085	0.0042	0.0053
Total Lead (µg)	9.6229	14.0286	39.7968	32.3349	26.096	26.096	30.9814	34.2426	36.0942	35.0812	76.2729	44.8525	53.2717	67.5835	43.512	44.3027
Net Lead (µg)	7.6729	12.0766	37.8468	30.3849	24.146	24.146	28.0314	32.2826	34.1442	33.1312	74.3229	42.8025	51.3217	65.6335	41.562	42.3527
Net Lead Concentration (µg/m ³)	0.0047	0.0074	0.0046	0.0037	0.0030	0.0030	0.0036	0.0040	0.0041	0.0042	0.0085	0.0053	0.0065	0.0083	0.0040	0.0051
Total Zinc Concentration (µg/m ³)	0.028	0.032	0.023	0.023	0.016	0.016	0.023	0.021	0.022	0.026	0.024	0.022	0.028	0.024	0.021	0.028
Total Zinc (µg)	45.658	52.192	180.693	190.693	130.48	130.48	187.519	171.213	184.668	207.298	210.408	179.41	222.628	180.824	217.56	234.052
Net Zinc (µg)	0.2	0.2	119.543	119.543	59.33	59.33	118.369	100.063	113.518	136.148	139.258	108.28	151.478	119.874	146.41	162.902
Net Zinc Concentration (µg/m ³)	0.2	0.2	0.014	0.014	0.007	0.007	0.014	0.012	0.014	0.017	0.016	0.013	0.018	0.015	0.014	0.019

GD = Sample obtained from the General Dynamics site

WS = Sample obtained from the White Settlement site

1 Cadmium was not detected in this sample at this reporting limit

2 Zinc concentration cannot be quantified due to the limited sample volume

NS = No sample was collected because of circuit failure

m³ = Cubic meter

µg = Microgram

NA = Not analyzed for

ND = Analyzed for but not detected

Table 1-114. (continued) Summary of Inorganic Contaminants in Air Samples

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INORGANIC CONTAMINANT	MAR 31		APR 08		APR 12		APR 18		APR 24		APR 30		MAY 08		MAY 12	
	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS
Sample Volume (m ³)	8082	8280	3875	8481	7851	8257	8359	8095	NS	NS	9664	9664	NS	NS	11299	10873
Total Particulates (µg/m ³)	22.0	14.0	6.3	18.0	23.0	24.0	11.0	15.0	NS	NS	19.0	17.0	NS	NS	18.0	18.0
Total Cadmium Concentration (µg/m ³)	0.00013	0.00013	0.00037	0.00018	0.00018	0.00018	0.00013	0.00018	NS	NS	0.00019	0.00017	NS	NS	0.00013	0.00016
Total Chromium Concentration (µg/m ³)	1.04806	1.0784	1.43375	1.52298	1.43118	1.32112	1.08687	1.0971	NS	NS	1.83816	1.84288	NS	NS	1.46887	1.63086
Net Cadmium (µg)	0.78306	0.8114	1.16875	1.25798	1.16618	1.05612	0.82167	0.8321	NS	NS	1.57116	1.37788	NS	NS	1.20387	1.36596
Net Chromium Concentration (µg/m ³)	0.00010	0.00010	0.00030	0.00015	0.00015	0.00013	0.00010	0.00014	NS	NS	0.00016	0.00014	NS	NS	0.00011	0.00013
Total Chromium Concentration (µg/m ³)	0.0018	0.0014	0.0042	0.0013	0.0031	0.0011	0.0021	0.0015	NS	NS	0.0020	0.00029	NS	NS	0.0011	0.00051
Total Chromium (µg)	14.5116	11.592	16.275	10.9883	24.6481	8.0827	17.5539	9.1425	NS	NS	19.328	2.80256	NS	NS	12.4289	5.54523
Net Chromium (µg)	9.0618	6.142	10.825	5.5493	19.1981	3.6327	12.1039	3.8925	NS	NS	13.878	-2.8474	NS	NS	8.9789	0.98523
Net Chromium Concentration (µg/m ³)	0.0011	0.0007	0.0028	0.0007	0.0024	0.0004	0.0014	0.0008	NS	NS	0.0014	-0.0003	NS	NS	0.0006	0.0000
Total Lead Concentration (µg/m ³)	0.0050	0.0061	0.0088	0.0056	0.0060	0.0068	0.0032	0.0046	NS	NS	0.0055	0.0055	NS	NS	0.0048	0.0049
Total Lead (µg)	40.31	50.508	34.1	47.3816	47.706	56.1478	26.7488	29.037	NS	NS	53.152	53.152	NS	NS	54.2352	53.2777
Net Lead (µg)	38.36	48.558	32.15	45.4316	45.756	54.1978	24.7988	26.087	NS	NS	51.202	51.202	NS	NS	52.2852	51.3277
Net Lead Concentration (µg/m ³)	0.0048	0.0059	0.0083	0.0054	0.0058	0.0066	0.0030	0.0043	NS	NS	0.0053	0.0053	NS	NS	0.0048	0.0047
Total Zinc Concentration (µg/m ³)	0.020	0.019	0.034	0.024	0.021	0.022	0.013	0.021	NS	NS	0.019	0.018	NS	NS	0.016	0.020
Total Zinc (µg)	161.24	157.32	131.75	203.064	166.971	181.654	108.667	127.995	NS	NS	183.616	173.952	NS	NS	180.784	217.46
Net Zinc (µg)	90.09	86.17	60.6	131.914	95.821	110.504	37.517	56.845	NS	NS	112.466	102.802	NS	NS	109.634	146.31
Net Zinc Concentration (µg/m ³)	0.011	0.010	0.016	0.016	0.012	0.013	0.004	0.009	NS	NS	0.012	0.011	NS	NS	0.010	0.013

m³ = Cubic meter

µg = Microgram

NA = Not analyzed for

ND = Analyzed for but not detected

GD = Sample obtained from the General Dynamics site

WS = Sample obtained from the White Settlement site

* Cadmium was not detected in this sample at this reporting limit

* Zinc concentration cannot be quantified due to the limited sample volume

NS = No sample was collected because of circuit failure

261268

mm³ = Cubic meter
 μg = Microgram
 NA = Not analyzed for
 ND = Analyzed for but not detected

WS = Sample obtained from the White Settlement site

2 Zinc concentration cannot be quantified due to the limited sample volume

NS = No sample was collected because of circuit failure

m³ = Cubic meter

μg = Microgram

NA = Not analyzed for

ND = Analyzed for but not detected

1.5.8.3 VOC Contaminants in Air

All VOC samples were analyzed for the target compound list of VOCs. Table 1-115 presents the analytical data and the frequency of detection for the 23 VOCs that were detected in the air samples from either location. Five compounds (chlorodifluoromethane, *cis*-1,2-dichloroethene, chloroform, n-nonane, and Freon 114) were only detected in one sample and, thus, do not represent a significant air contaminant. Eight additional compounds (chloromethane, carbon tetrachloride, tetrachloroethene, chlorobenzene, ethylbenzene, *m*- and/or *p*-xylene, *o*-xylene, and styrene) were detected in the offsite samples at the same frequency and concentrations as in the onsite samples and thus do not represent a significant air contaminant. It should be noted that the concentrations of xylenes at the onsite sample are generally higher when the wind is from the south than when it is from other directions, primarily north. This indicates a lack of activity that can be directly associated with the presence of Lake Worth.

Concentrations of the ten remaining compounds vary widely in the samples collected from both locations. The frequency of detection at the offsite location for each of these compounds roughly equals that of the onsite location, however, the concentrations seen from the onsite samples are generally significantly higher than those seen from the offsite samples. This difference ranges from a factor of 2 for methylene chloride, benzene, toluene, trichlorofluoromethane, 1,3,5-trimethylbenzene, and 1,2,4-trimethylbenzene, up to an order of magnitude for dichlorodifluoromethane, Freon 113, 1,1,1-TCA, and TCE. These differences indicate that the activities at Plant 4 are contributing significantly to the levels of the aforementioned contaminants in the air. Appendix I-1 of the RI provides the analytical data reports.

Wind direction appears to have little effect on the downwind concentrations of dichlorodifluoromethane and 1,1,1-trichloroethane, indicating that there are sources of these compounds located both north and south of the on-site air monitoring station location. In contrast, significant increases in concentrations are noted for Freon 113 and trichloroethene when the winds are blowing from the south (the predominant wind direction at Plant 4).

1.5.8.4 Total Particulates and Metal Contaminants in Air

All particulate sample filters were analyzed for total particulates, cadmium, chromium, lead, and zinc. Table 1-114 presents a summary of the analytical data and the frequency of detection for the analyses performed. Concentrations of these analytes vary widely in the samples collected from both locations. Wind direction appears to have little effect on the concentrations noted at both sites based on the five-day period wind direction frequencies depicted in Table 1-113. When evaluated, these data indicate that no significant increase in analyte concentrations is noted due to the activities at Plant 4. Appendix I-1 of the RI provides the analytical data reports.

Table 1-115. Summary of Organic Contaminants in Air Samples

SAMPLE DATE CONTAMINANT (ppb)	FEB 11		FEB 18		FEB 24		MAR 01		MAR 07		MAR 13		MAR 19		MAR 25	
	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS
Dichlorodifluoromethane	0.66	0.46	3.30	0.60	11.00	0.57	1.90	0.61	1.00	0.54	2.00	0.60	1.10	0.54	3.00	0.64
Chlorodifluoromethane	0.56	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chloromethane	<0.50	<0.50	<1.00	<0.50	<0.50	<0.50	0.62	0.61	0.55	0.59	0.49 J	0.48 J	0.48 J	0.58 J	0.50	0.58
Freon 113 ¹	2.80 B	<0.20	<0.40	0.10 J	0.34	0.13 J	0.59	0.10 J	1.40	<0.20	1.30	0.21	0.13 J	0.10 J	0.34	0.29
Methylene Chloride	0.20	0.14 J	<0.40	<0.20	<0.20	0.15 J	0.22	0.14 J	0.18 J	0.14 J	0.20	0.18 J	0.24 J	0.14 J	0.19 J	0.18 J
cis-1,2-Dichloroethane	<0.30	<0.30	<0.60	<0.30	<0.30	<0.30	0.10 J	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Chloroform	0.10 J	<0.30	<0.60	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
1,1,1-Trichloroethane	0.78	0.28 J	<0.60	0.22 J	0.31	0.30 J	0.41	0.23 J	0.52	0.24 J	0.57 B	0.45 B	0.32 B	0.32 B	0.40 J	0.39
Carbon Tetrachloride	0.10 J	0.10 J	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Benzene	0.45	0.39	0.74	0.67	0.59	0.66	0.86	0.36	1.00	0.46	0.75	0.78	0.31	0.40	0.62	0.70
Trichloroethene	2.80	<0.20	<0.40	<0.20	<0.20	<0.20	0.43	<0.20	0.99	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.34
Toluene	2.80	0.55	1.30	1.10	1.00	1.10	2.30	0.50	3.30	0.72	2.10	1.40	0.44	0.60	1.20 B	1.30 B
Tetrachloroethane	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	0.59	0.17 J	<0.20	0.24	0.20	<0.20	<0.20	0.16 J	0.10 J
Chlorobenzene	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	0.11 J	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	0.41	0.17 J	0.21 J	0.29	0.16 J	0.23	0.38	0.24	0.55	0.38	0.37	0.48	<0.20	0.53	0.16 J	0.52
m + p-Xylene	1.80	0.62	0.84	1.20	0.52	0.92	1.40	1.10	2.00	1.80	1.30	1.90	0.25	2.30	0.61	2.20
n-Nonane	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
o-Xylene	0.50	0.16 J	0.32 J	0.36	0.20	0.28	0.51	0.24	0.71	0.38	0.48	0.75	<0.20	0.94	0.25	0.84
Styrene	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	0.14 J	<0.20	<0.20	0.21	<0.20	0.11 J	<0.20	<0.20
Freon 114 ²	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trichlorofluoromethane	5.70	0.57	0.36 J	0.22	0.26	0.29	0.60	0.27	0.48	0.27	0.44	0.31	0.26	0.36	0.30	0.43
1,3,5-Trimethylbenzene	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.10 J	0.13 J	<0.20	<0.20	<0.20	<0.20
1,2,4-Trimethylbenzene	0.18 J	0.14 J	0.35 J	0.29	0.21	0.25	0.44	0.14 J	0.55	0.20	0.37	0.43	0.12 J	0.25	0.26	0.37

B = Detected in analytical method blank

J = Detected at or below the analytical method reporting limit

NA = Not analyzed for

ND = Analyzed for but not detected

NS = No sample was collected because of circuit failure

GD = Sample obtained from the General Dynamics site

WS = Sample obtained from the White Settlement site

ppb = Parts per billion (volume per volume)

¹Freon 113 = 1,1,2-Trichloro-1,2,2-Trifluoroethane²Freon 114 = 1,2-Dichloro-1,1,2,2-Tetrafluoroethane

Table 1-115. (continued) Summary of Organic Contaminants in Air Samples

CONTAMINANT (ppb)	MAR 31		APR 06		APR 12		APR 18		APR 24		APR 30		MAY 06		MAY 12	
	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS	GD	WS
Dichlorodifluoromethane	6.30	0.77	3.70	0.37	1.70	0.28	0.32	0.22	NS	NS	1.80	0.35	0.23	0.14 J	0.29	0.42
Chlorodifluoromethane	<0.20	<0.20	<0.20	<0.20	<2.00	<0.20	<0.20	<0.20	NS	NS	NA	NA	NA	<0.20	<0.20	<0.20
Chloromethane	0.52	0.55	<0.50	<0.50	<5.00	<0.50	<0.50	<0.50	NS	NS	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Freon 113 ¹	0.48	0.28	0.42	0.29 J	4.40	0.11 J	0.80	<0.20	NS	NS	1.80 J	0.16 J	0.12 J	0.12 J	0.11 J	0.79
Methylene Chloride	0.48	0.25	0.16 J	0.17 J	<2.00	<0.20	0.15 J	<0.20	NS	NS	0.30 J	0.21	0.14 J	0.17 J	<0.20	0.15 J
cis-1,2-Dichloroethane	<0.30	<0.30	<0.30	<0.30	<3.00	<0.30	<0.30	<0.30	NS	NS	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Chloroform	<0.30	<0.30	<0.30	0.07 J	<3.00	<0.30	<0.30	<0.30	NS	NS	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
1,1,1-Trichloroethane	0.69 B	0.48 B	0.45 B	0.44 B	2.50 B	0.30 B	0.59 B	0.27 JB	NS	NS	0.72 B	0.43 B	0.33 B	0.34 B	0.34 B	0.51 B
Carbon Tetrachloride	0.10 J	0.10 J	0.11 J	0.11 J	<2.00	0.10 J	0.10 J	0.10 J	NS	NS	0.11 J	0.11 J	0.11 J	0.11 J	0.11 J	0.12 J
Benzene	0.94	0.94	0.74	0.74	1.00 J	0.34	0.31	0.26	NS	NS	1.50	1.10	0.25	0.70	0.39	0.38
Trichloroethene	0.20	0.33	<0.20	0.26	2.60	<0.20	2.30	<0.20	NS	NS	0.54	0.15 J	<0.20	<0.20	<0.20	0.64
Toluene	2.10 B	2.10 B	1.50	1.30	4.10	0.58	1.40	0.50	NS	NS	4.10	2.40	0.58	1.20	0.85	1.40
Tetrachloroethene	0.50	0.32	0.33	0.25	<2.00	<0.20	<0.20	<0.20	NS	NS	0.41	0.30	<0.20	<0.20	<0.20	<0.20
Chlorobenzene	<0.20	<0.20	<0.20	<0.20	<2.00	<0.20	0.15 J	<0.20	NS	NS	0.13 J	<0.20	0.11 J	<0.20	<0.20	0.14 J
Ethylbenzene	0.35	0.61	0.19 J	0.39	<2.00	0.22	0.36	0.24	NS	NS	0.66	0.75	0.25	0.38	0.68	0.19 J
m +/or p-Xylene	1.20	2.50	0.62	1.60	2.00	0.95	1.20	1.10	NS	NS	2.10	2.30	0.10 J	1.50	2.60	0.63
n-Nonane	<0.20	<0.20	<0.20	<0.20	0.71 J	<0.20	<0.20	<0.20	NS	NS	NA	NA	NA	NA	<0.20	<0.20
o-Xylene	0.46	0.97	0.24	0.60	<2.00	0.37	0.50	0.44	NS	NS	0.84	0.90	<0.20	0.62	1.10	0.24
Styrene	0.12 J	0.16 J	<0.20	0.05 J	<2.00	<0.20	<0.20	<0.20	NS	NS	0.10 J	0.13 J	<0.20	<0.20	<0.20	<0.20
Freon 114 ²	<0.20	<0.20	0.05 J	<0.20	<2.00	<0.20	<0.20	<0.20	NS	NS	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trichlorofluoromethane	0.35	0.61	0.27	0.29	0.36 J	0.27	0.32	0.25	NS	NS	0.32	0.28	0.26	0.25	0.29	0.34
1,3,5-Trimethylbenzene	0.14 J	0.16 J	0.07 J	0.09 J	0.37 J	0.04 J	0.21	<0.20	NS	NS	0.25	0.17 J	<0.20	<0.20	0.89	<0.20
1,2,4-Trimethylbenzene	0.48	0.53	0.23	0.32	0.59 J	0.14 J	0.78	0.15 J	NS	NS	0.84	0.60	<0.20	0.19 J	1.10	<0.20

B = Detected in analytical method blank

GD = Sample obtained from the General Dynamics site

WS = Sample obtained from the White Settlement site

ppb = Parts per billion (volume per volume)

¹ Freon 113 = 1,1,2-Trichloro-1,2,2-Trifluoroethane² Freon 114 = 1,2-Dichloro-1,1,2,2-Tetrafluoroethane

NA = Not analyzed for

ND = Analyzed for but not detected

NS = No sample was collected because of circuit failure

Table 1-115. (continued) Summary of Organic Contaminants in Air Samples

CONTAMINANT (ppb)	ONSITE - General Dynamics			OFFSITE - White Settlement		
	# of Hits # of Samples	Concentrations		# of Hits # of Samples	Concentrations	
		Min.	Max.		Min.	Max.
Dichlorodifluoromethane	15/15	.23	11.0	15/15	.14J	.77
Chlorodifluoromethane	1/13	ND	.56	0/13	ND	NA
Chloromethane	8/15	ND	.62	6/15	ND	.81
Freon 113	14/15	.34	4.40	12/15	ND	.79
Methylene Chloride	11/15	ND	.48	12/15	ND	.25
cis-1,2-Dichloroethane	1/15	ND	.10J	0/15	ND	NA
Chloroform	1/15	ND	.10J	1/15	ND	.07J
1,1,1-Trichloroethane	14/15	.31	2.508	15/15	.22J	.518
Carbon Tetrachloride	7/15	ND	.11J	8/15	ND	.12J
Benzene	15/15	.25	1.50	15/15	.26	1.10
Trichloroethane	7/15	ND	2.80	5/15	ND	.64
Toluene	15/15	.44	4.10	15/15	.50	2.40
Tetrachloroethane	8/15	ND	.50	6/15	ND	.59
Chlorobenzene	4/15	ND	.15J	1/15	ND	.14J
Ethylbenzene	13/15	ND	.68	15/15	.17J	.75
m +/or p-Xylene	15/15	.10J	2.60	15/15	.62	2.50
n-Nonane	1/13	ND	.71J	0/13	ND	NA
o-Xylene	12/15	ND	1.10	15/15	.16J	.97
Styrene	3/15	ND	.14J	5/15	ND	.21
Freon 114	1/15	ND	.05J	0/15	ND	NA
Trichlorofluoromethane	15/15	.26	5.70	15/15	.22	.61
1,3,5-Trimethylbenzene	7/15	ND	.69	5/15	ND	.17J
1,2,4-Trimethylbenzene	14/15	ND	1.10	14/15	ND	.60
						0.47
						NA
						0.38
						0.20
						0.15
						NA
						0.07
						0.35
						0.10
						0.59
						0.18
						1.12
						0.18
						0.10
						0.37
						1.51
						NA
						0.54
						0.11
						NA
						0.33
						0.11
						0.27

B = Detected in analytical method blank

J = Detected at or below the analytical method reporting limit

NA = Not analyzed for

ND = Analyzed for but not detected

NS = No sample was collected because of circuit failure

GD = Sample obtained from the General Dynamics site

WS = Sample obtained from the White Settlement site

ppb = Parts per billion (volume per volume)

Freon 113 = 1,1,2-Trichloro-1,2,2-Trifluoroethane

Freon 114 = 1,2-Dichloro-1,1,2,2-Tetrafluoroethane

1.6 Contaminant Fate and Transport

1.6.1 Introduction

The fate and transport of contaminants at Plant 4 were assessed to facilitate the Baseline Risk Assessment (see Section 1.7) and to provide data to support the evaluation of remedial alternatives in the FS. Components of the assessment included (1) an evaluation of the physicochemical properties of the organic chemicals of concern (COCs) at the site, (2) an evaluation of physicochemical processes resulting in contaminant transformation, (3) an evaluation of contaminant transport mechanisms, and (4) numerical modeling of contaminant transport.

1.6.2 Contaminant Fate

In analysis of contaminant fate, knowledge of the physicochemical properties of COCs is combined with knowledge of physicochemical processes to form a qualitative representation of the environmental fate of the COCs. The physicochemical properties and processes impacting contaminant fate are discussed in the following sections.

1.6.2.1 Physicochemical Properties

Physical and chemical properties that are helpful in understanding which processes will be important under environmental conditions are solubility, specific gravity, vapor pressure, Henry's Law constant (H), octanol/water partition coefficient (K_{ow}), and the organic carbon/water partition coefficient (K_{oc}). Table 1-116 lists the physicochemical properties of the organic chemicals of human-health and environmental concern identified in the various media at Plant 4.

Solubility

Solubility in water is the saturated concentration of a compound in pure water at a given temperature and pressure. Above this concentration, two phases exist: a saturated aqueous phase and a solid or a liquid phase (a nonaqueous phase liquid [NAPL]). Solubility in water is affected by temperature, salinity, dissolved organic matter, and pH (Lyman and others 1982). Compounds with high water solubility tend to be distributed to a wider extent, have low soil adsorption coefficients, have low bioconcentration factors, and are less likely to volatilize than compounds with low water solubility. Water solubility may also affect transformation by photolysis, hydrolysis, oxidation/reduction, and biodegradation (Howard 1990).

On the basis of their solubilities, benzene, 1,1-dichloroethane, 2,4-dimethylphenol, methylene chloride, methylphenol, 1,1,1-TCA, and TCE would be expected to be the most mobile of the organic COCs. Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and pyrene would be expected to be the least mobile (see Table 1-116).

Cosolvency is a process whereby the solubility of a solute in water increases when an organic solvent is present (Leinonen and MacKay 1973). Experimental results show that the cosolvent must be at concentrations greater than 5×10^{-3} on a mole fraction basis for the cosolvency effect to be significant.

Table 1-116. Physicochemical Properties of Organic Chemicals of Concern Identified at Plant 4

Chemical	Solubility mg/L (°C)	Specific Gravity Unitless (°C)	Vapor Pressure mm (°C)	Henry's Law Constant atm • m ³ /mole (°C)	Log K _{ow}	Log K _{oc}
Acenaphthene	3.47 (25°)	1.0242 (90/4°)	1.55x10 ⁻³ (25°)	1.5x10 ⁻⁴	3.92-4.33	1.25
Benzene	1,780 (20°)	0.8786 (20/4°)	76 (20°)	5.48x10 ⁻³ (25°)	2.13	1.82
Benzo(a)anthracene	0.057 (20°)	1.274 (20/4°)	22x10 ⁻⁶ (20°)	6.6x10 ⁻⁷	5.81-5.91	6.14
Benzo(a)pyrene	3.8x10 ⁻³ (25°)	1.351	5.48x10 ⁻⁶ (25°)	4.9x10 ⁻⁷ (25°)	5.81-6.50	5.60-6.29
Benzo(b)fluoranthene	0.014 (25°)	No Data Found	5x10 ⁻⁷ (20°)	1.2x10 ⁻⁶ (20-25°)	6.57	5.74
Benzo(k)fluoranthene	5.5x10 ⁻⁴ (25°)	No Data Found	9.59x10 ⁻¹¹ (25°)	1.04x10 ⁻³	6.85	6.64
Chrysene	0.008 (25°)	1.274 (20/4°)	6.3x10 ⁻⁷ (20°)	7.26x10 ⁻²⁰	5.60-5.81	5.39
cis-1,2-Dichloroethene	800 (20°)	1.28	200 (25°)	3.37x10 ⁻³	1.86	1.69
1,2-Dichlorobenzene	100 (20°)	1.305 (20/4°)	1 (20°)	1.2x10 ⁻³ (20°)	3.38	2.26-3.23
1,4-Dichlorobenzene	49 (22°)	1.458 (20/4°)	0.6 (20°)	1.5x10 ⁻³ (20°)	3.39	2.20
1,1-Dichloroethane	5,500 (20°)	1.174 (20/4°)	180 (20°)	5.87x10 ⁻³	1.79	1.48
1,1-Dichloroethene	400 (20°)	1.218 (20/4°)	500 (20°)	0.0301	2.13	1.81
trans-1,2-Dichloroethene	800 (20°)	1.26	340 (25°)	6.72x10 ⁻³	2.06	1.77
2,4-Dimethylphenol	4,200 (20°)	1.036 (20/4°)	0.062 (20°)	1.7x10 ⁻⁵ (20-25°)	2.30-2.50	2.07
Ethylbenzene	161 (25°)	0.867 (20/4°)	7 (20°)	8.44x10 ⁻³	3.15	1.88-2.41
Fluoranthene	0.265 (25°)	1.252 (0/4°)	0.01 (20°)	0.0168 (25°)	5.22	4.62
Freon 113	170 (25°)	1.56	270 (20°)	0.526 (25°)	3.16	No Data Found
Methylene Chloride	20,000 (20°)	1.3266 (20/4°)	349 (20°)	2.68x10 ⁻³	1.25	0.94
2-Methylnaphthalene	24.6 (25°)	1.0058 (20/4°)	No Data Found	No Data Found	3.86-4.11	3.87-3.93
Methylphenol	24,500 (20°)	1.047 (20/4°)	0.24 (25°)	1.6x10 ⁻⁶	1.95	1.34
Naphthalene	30	1.152	0.82 (25°)	4.83x10 ⁻⁴	3.01-3.45	2.74-3.52
Phenanthrene	0.816 (21°)	1.179 (20/4°)	2.1x10 ⁻⁴ (20°)	2.56x10 ⁻⁴ (25°)	4.16-4.57	3.72-4.59
Pyrene	0.032 (24°)	1.271 (23/4°)	6.85x10 ⁻⁷ (25°)	1.09x10 ⁻⁶	4.88-5.32	4.66-5.13
Toluene	515 (20°)	0.867 (20/4°)	22 (20°)	5.94x10 ⁻³	2.69	2.06-2.18
1,1,1-Trichloroethane	4,400 (20°)	1.35 (20/4°)	100 (20°)	8x10 ⁻³	2.49	2.017-2.18
Trichloroethene	1,100 (25°)	1.4642 (20/4°)	80 (20°)	1.03x10 ⁻²	2.42	1.81-2.10
1,2,4-Trimethylbenzene	57 (20°)	0.88	No Data Found	No Data Found	No Data Found	No Data Found
1,3,5-Trimethylbenzene	No Data Found	0.865	No Data Found	No Data Found	No Data Found	No Data Found
Vinyl Chloride	1,100 (25°)	0.9121 (15/4°)	2,660 (25°)	1.07x10 ⁻²	1.38	0.39
m-Xylene	146 (25°)	0.864	6 (20°)	7.68x10 ⁻³	3.20	3.20
o-Xylene	175 (25°)	0.88	5 (20°)	5.1x10 ⁻³	2.77	2.11
p-Xylene	156 (25°)	0.86	6 (20°)	7.68x10 ⁻³	3.15	2.31

Sources:

1. Howard, P.H., 1990, *Handbook of Environmental Fate and Exposure Data for Organic Chemicals*, Lewis Publishers, Inc., 2 volumes.
2. Montgomery, J.H., and Welton, L.M., 1990, *Groundwater Chemicals Desk Reference*, Lewis Publishers, Inc.
3. U.S. Environmental Protection Agency (EPA), 1986, *Superfund Public Health Evaluation Manual*, EPA/540/1-88/001, Office of Solid Waste and Emergency Response Directive 9285.4-1.
4. EPA, 1982, *Aquatic Fate Process Data for Organic Priority Pollutants*, Final Report, 407 pp.
5. Verschuuren, K., 1983, *Handbook of Environmental Data on Organic Chemicals*, Van Nostrand Reinhold, Second Edition.

Specific Gravity

Specific gravity, or specific density, is the ratio of the mass of a given volume of a compound at a specified temperature, to the mass of the same volume of water at a given temperature. The temperatures of the compound and of water are indicated by in parenthesis after the value for specific gravity (see Table 1-116). An immiscible compound with a specific gravity greater than 1 (a DNAPL) will sink in water, and an immiscible compound with a specific gravity less than 1 (an LNAPL) will float on water.

Benzene, ethylbenzene, toluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, vinyl chloride, and *m*-, *o*-, and *p*-xylenes have specific gravities less than 1, and, therefore, will tend to form LNAPLs when their solubility in water is exceeded (see Table 1-116). The remaining chemicals in Table 1-116 have specific gravities greater than 1 and will tend to form DNAPLs when their solubility in water is exceeded.

Vapor Pressure

The vapor pressure is the pressure exerted by the vapor phase of a compound in equilibrium with the liquid or solid phase at a given temperature. Vapor pressure values provide a means of assessing the relative volatility of pure compounds. Vapor pressure data and solubility data are used to determine values of *H*, which describe the volatilization of chemicals from water.

Compounds with relatively low vapor pressures, high adsorption on solids, or high solubility in water are less likely to vaporize than compounds with high vapor pressures, low adsorption to solids, or low water solubility. The latter chemicals are less likely to biodegrade or hydrolyze but have a higher potential to undergo significant photolysis. Nonvolatile compounds are less frequently involved in significant atmospheric transport, so an analysis of their fate should focus on soil and water processes (Verschueren 1983).

Benzo(k)fluoranthene has the lowest vapor pressure, 9.57×10^{-11} millimeter (mm), of the organic COCs listed in Table 1-116. Vinyl chloride is the organic COC with the highest vapor pressure, 2,660 mm Hg at 25°C.

Henry's Law Constant

Henry's Law constant (*H*) also referred to as the air/water partition coefficient, is the ratio of atmospheric concentration of a compound expressed in atmospheres (atm) to the solution concentration expressed in moles per cubic meter (mol/m^3). The larger the *H* value, the more the compound will tend to partition into the vapor phase. Compounds with an *H* value less than $10^{-7} \text{ atm}\cdot\text{m}^3/\text{mol}$ are essentially nonvolatile. Compounds with an *H* value between 10^{-7} and $10^{-5} \text{ atm}\cdot\text{m}^3/\text{mol}$ volatilize slowly. If a compound's *H* value lies between 10^{-5} and $10^{-3} \text{ atm}\cdot\text{m}^3/\text{mol}$, then volatilization is a significant transfer mechanism. Compounds with an *H* value greater than $10^{-3} \text{ atm}\cdot\text{m}^3/\text{mol}$ are considered to be highly volatile.

Chrysene is the only organic COC with an *H* value less than $10^{-7} \text{ atm}\cdot\text{m}^3/\text{mol}$ and, therefore, considered nonvolatile (see Table 1-116). The organic COCs expected to volatilize slowly include benzo(a)anthracene, benzo(a)pyrene, and methylphenol. Volatilization is considered a significant transfer mechanism for acenaphthene, benzo(b)fluoranthene, 2,4-dimethylphenol, naphthalene,

phenanthrene, and pyrene. All remaining organic COCs have H values greater than 10^{-3} atm·m³/mol and, therefore, are considered highly volatile. The process of volatilization is discussed further in Section 1.6.2.2.

Octanol/Water Partition Coefficient (K_{ow})

The K_{ow} is the ratio of a compound's concentration in octanol to its concentration in water in a two-phase (octanol and water) system. K_{ow} is measured at low solute concentrations where it is a weak function of solute concentration. At solute concentrations much greater than 0.01 moles per liter (mol/L), K_{ow} is a function of solute concentration (Lyman and others 1982). Because values of K_{ow} can span several orders of magnitude, K_{ow} is usually expressed in terms of the logarithm of K_{ow} ($\log K_{ow}$). K_{ow} is an indicator of a compound's hydrophobicity and can be correlated with soil/sediment adsorption coefficients and bioconcentration factors (Howard 1990). Compounds with K_{ow} values less than 10 ($\log K_{ow} < 1$) are considered relatively hydrophilic and tend to have high solubilities in water. Compounds with K_{ow} values greater than 10^4 ($\log K_{ow} > 4$) are very hydrophobic (Lyman and others 1982).

All of the organic COCs have $\log K_{ow}$ values less than 10 and, therefore, tend to have high solubilities in water (see Table 1-116). Benzo(k)fluoranthene has the highest $\log K_{ow}$ value, 6.85, and methylene chloride has the lowest $\log K_{ow}$ value, 1.25.

Organic Carbon/Water Partition Coefficient (K_{oc})

The K_{oc} is the ratio of the amount of a compound adsorbed per unit mass organic carbon in the soil or sediment to the concentration of the compound in solution at equilibrium. K_{oc} values are used in estimating the partitioning of a compound onto soil or sediment on the basis of empirical data, which indicates that adsorption of a compound often depends on the mass of organic carbon in the soil. For this reason, K_{oc} is often referred to as the soil/sediment partition coefficient. As with K_{ow} , K_{oc} values span several orders of magnitude and are usually expressed in terms of the $\log K_{oc}$.

1.6.2.2 Physicochemical Processes

Physicochemical processes include the physical, chemical, and biological mechanisms by which organic chemicals and inorganic constituents transform from one physical phase to another or degrade to form new compounds. The primary physicochemical processes impacting the environmental fate of the constituents at Plant 4 are discussed in the following sections.

Volatilization

Volatilization, the evaporative loss of a chemical, depends upon the vapor pressure, solubility, and diffusivity coefficients of the chemical. Volatilization is also dependent on environmental conditions (temperature, water depth, soil moisture, air flow rate over the surface, and humidity) and on modifying materials (absorbants, emulsions) that influence diffusion from the evaporative surface. The effect of a rise in temperature on volatilization is variable. In general, an increase in temperature usually increases the vapor concentration. However, for compounds for which adsorption is an endothermic process, an increase in temperature will decrease the vapor concentration (Lyman and others 1982). Air flow increases the volatilization rate by removing vapor from the surface faster

than molecular diffusion. Volatilization decreases under conditions of low humidity because sorption is increased as soil water content is decreased.

Volatilization is an important process contributing material for airborne transport that may lead to the distribution of a chemical over wide areas. As discussed in Section 1.6.2.1, compounds with relatively low vapor pressures, high adsorptivity onto solids, or high solubility in water are less likely to vaporize and become airborne than chemicals with high vapor pressures or with less affinity for solution in water or adsorption to solids and sediments.

Volatilization at the interface between the capillary fringe and the unsaturated zone can be approximated by the value of H . Studies indicate that the value of H should be greater than approximately 0.005 to 0.024 atm·m³/mol for significant volatilization from an aquifer to the unsaturated zone to occur (Kerfoot 1988). A comparison of H values can be used to predict that benzene, 1,1-DCA, 1,1-DCE, *trans*-1,2 DCE, ethylbenzene, fluoranthene, freon, toluene, 1,1,1-TCA, TCE, and vinyl chloride are the organic COCs with the greatest tendency for volatilization from the aquifer to the unsaturated zone (see Table 1-116).

Adsorption

Adsorption onto solids is an important aspect of compound transport because it reduces chemical mobility in both solution and vapor phases. Conversely, desorption from solids increases chemical concentration in solution and vapor phases. Adsorption may be fully or partially reversible. For weakly polar or nonionic compounds, soil moisture acts to displace the compounds from surfaces of soil particles increasing the concentration of the compounds in the soil gas. As the soil dries, weakly polar or nonionic compounds are sorbed onto the soil (Lyman and others 1982).

The mass of a compound adsorbed to the soil has been shown to be directly related to the soil particle surface area and organic matter content in the soil (Lyman and others 1982). In particular, the sorption of nonpolar organic compounds to soil is significantly affected by the organic carbon content of soils (Jury and Valentine 1986). At least 0.1 percent of organic carbon content (fraction organic carbon [f_{oc}] greater than 0.001) in aquifer sediments is required for carbon adsorption to be significant (Newsom 1985).

The amount of a given organic compound adsorbed to soils varies directly with its K_{ow} and inversely with its solubility in water (Newsom 1985; Karickhoff, Brown, and Scott 1979). Generally, for solute concentrations less than 0.01 millimolar, linear isotherms are produced, and the distribution coefficient (K_d) will describe partitioning between liquids and solids. Above the 0.01 millimolar concentration limit, sorption may be nonlinear, and Freundlich or Langmuir isotherms are needed to describe solute behavior. The empirically derived Freundlich equation is

$$S = K_d C^b \quad \text{Equation 1-3}$$

"where S is the mass of the solute species adsorbed or precipitated on the solids per unit bulk dry mass of the porous medium, C is the solute concentration, and K_d and b are coefficients that depend on the solute species, nature of the porous medium, and other conditions" (Freeze and Cherry 1979).

K_d can be related to the fraction organic carbon of the soil and to the K_{oc} of the compound by the equation

$$K_d = f_{oc} K_{oc} \quad \text{Equation 1-4}$$

(Ward and others 1985).

For volatile halogenated organic compounds, K_d may also be predicted by

$$\log K_d = 0.72 \log K_{ow} + \log f_{oc} + 0.5 \quad \text{Equation 1-5}$$

(Ward and others 1987).

Laboratory studies have documented that a large proportion of adsorption of organic compounds takes place on silt- and clay-sized particles. The quantity of material adsorbed is directly related to the surface area of the solid (Hem 1985) or to the particle size and particle size distribution and associated organic carbon content (Karickhoff and others 1979). It is difficult to distinguish the effects of adsorption of organic compounds on the mineral fraction from the adsorption by the mass-fraction organic carbon. No quantitative method for determining adsorption of organic COCs onto mineral surfaces has yet been devised.

When a solute adsorbs to a solid, its velocity with respect to the velocity of groundwater is retarded. The degree of retardation is described by the retardation factor, R , where

$$R = 1 + \frac{\rho_b K_d}{n} = \frac{v}{v_c} \quad \text{Equation 1-6}$$

and ρ_b is the bulk mass density, n is the porosity, K_d is the distribution coefficient, and v/v_c is the ratio of velocities of a conservative tracer to a sorbing solute. A retardation factor equal to 1 means that a solute velocity is not retarded (the solute velocity equals groundwater velocity).

Attempts were made to quantify K_d values using field measurements for various contaminants identified in the alluvial aquifer at Plant 4. Contaminant concentrations in soil samples collected at various depths during drilling and in groundwater during subsequent well sampling were used to calculate K_d estimates using the following equation:

$$K_d = \frac{C_s}{C_L} \quad \text{Equation 1-7}$$

where C_s is the contaminant concentration in micrograms in the solid phase per gram of solid, and C_L is the contaminant concentration in the liquid phase in micrograms per liter of liquid (Equation 12.33; Domenico and Schwartz 1990).

However, the resulting K_d estimates were highly variable across the site, and an accurate estimate could not be obtained. This result is not surprising because Equation 1-7 assumes the concentrations in the discrete solid and liquid phases are known. However, complete separation of the solid and liquid phases prior to analysis is logistically impossible. As a result, only a total contaminant concentration within the coexisting solid and liquid phases is measured. The mass of contaminant contributed to the total concentration by residual water in the soil can be significant, especially for weakly adsorbed (low K_d) compounds. Correction of Equation 1-7 for the contaminant contributed by water trapped within the soil requires moisture content measurements, which were not performed during soil analysis.

Although quantitative estimates of K_d could not be obtained, K_{oc} values can be used to qualitatively assess both K_d and R values for the organic COCs listed in Table 1-116. Given a mean f_{oc} value for soil at the site, Equation 1-4 indicates that K_d is directly proportional to K_{oc} . Similarly, given a porosity and bulk mass density of the soil, Equation 1-6 indicates that R is primarily influenced by K_d . Therefore, chemicals with high K_{oc} values will exhibit higher K_d and R values than chemicals with low K_{oc} values. Of the chemicals listed in Table 1-116, vinyl chloride ($K_{oc} = 0.39$) is expected to have the lowest K_d and R values, and benzo(k)fluoranthene is expected to have the highest K_d and R values.

Photolysis

Photolysis is a chemical transformation process whereby a compound is broken down directly by absorbing a photon of light or indirectly by reacting with a sensitized humic substance or with a photochemical oxidant, such as hydroxyl and peroxy radicals and singlet oxygen (Swann and Eschenroeder 1983). The rate of photolysis is affected by the organic compound's photochemical reactivity, its extent of light absorption, and the properties of the environment, such as the intensity and spectrum of solar radiation. For these reasons, photolysis is generally important only in surface waters, soils, and the atmosphere.

The following organic COCs are capable of undergoing direct photolysis (Howard 1990; EPA 1982):

acenaphthene	chrysene	naphthalene
benzo(a)anthracene	2,4-dimethylphenol	phenanthrene
benzo(a)pyrene	fluoranthene	pyrene
benzo(b)fluoranthene	2-methylnaphthalene	
benzo(k)fluoranthene	methylphenol	

Several of the remaining organic COCs listed in Table 1-116 are capable of undergoing indirect photolysis. For example, benzene, ethylbenzene, and toluene will react with photochemically derived hydroxyl radicals with half-lives of 13.4 days, 0.5 hours to two days, and three hours to one day, respectively. Products of benzene photolysis include phenol, formic acid, nitrophenols, nitrobenzene, and peroxyacetyl nitrate. Products of ethylbenzene photolysis include ethylphenol, benzaldehyde, acetophenone, and *m*- and *p*-ethyl-nitrobenzene. Products of toluene photolysis include nitrophenols, nitrocresols, nitrotoluenes, cresols, benzaldehyde, and benzyl nitrate (Howard 1990). TCE, *cis*- and *trans*-1,2-DCE, and 1,1-DCE also react with photochemically derived hydroxyl radicals with half-lives of up to eight days. TCE photolysis produces phosgene, dichloroacetyl chloride, and formyl chloride; photolysis of *cis*- and *trans*-1,2-DCE produces formyl chloride; and photolysis of 1,1-DCE

produces chloroacetyl chloride, phosgene, formaldehyde, formic acid, hydrochloric acid, carbon monoxide, and nitric acid (Howard 1990).

Hydrolysis

Hydrolysis refers to the reaction of an organic compound with water resulting in the formation of a new carbon-oxygen bond and the elimination of a leaving group (chloride, bromide, phenoxide, etc.) (Lyman and others 1982). At environmental pHs (pH 5 to 9), hydrolysis may be significant for alkyl halides, amides, carbamates, carboxylic acids, epoxides and lactones, phosphate esters, and sulfonic acid esters (Howard 1990). Data are not available on the hydrolytic half-lives of the organic COCs listed in Table 1-116; however, these compounds are expected to be resistant to hydrolysis in natural waters (EPA 1979; Howard 1990).

Oxidation/Reduction

Organic compounds generally undergo oxidation reactions; however, halogenated compounds tend to undergo reduction reactions because of the electronegative nature of the halogen atoms. Metals may undergo oxidation or reduction reactions. For example, hexavalent chromium may be reduced to trivalent chromium, or trivalent chromium may be oxidized to hexavalent chromium. In either case, the chromium cation may combine with anions in the groundwater or with negatively charged particles and precipitate out of solution.

Biotransformation

Biotransformation converts organic compounds into new organic compounds that may be either innocuous or toxic. If inorganic compounds are formed, the conversion is termed mineralization. Biotransformation can occur through the action of microorganisms attached to soil particles or suspended in groundwater (Kobayashi and Rittman 1982). The potential for biodegradation of a particular compound depends on the types and number of microorganisms present in the soil, the physiological capabilities of the microorganisms, the acclimatization of the microorganisms, the chemical character and concentration of the compound, and the geochemical environment of the unsaturated or saturated zone.

Chemical characteristics that affect biodegradability include the compound's solubility, vapor pressure, and K_{ow} . Insoluble compounds are not readily available to organisms for biodegradation (Kobayashi and Rittman 1982). High concentrations of a compound may be toxic to organisms while low concentrations may yield insufficient energy to sustain continued microbial growth (Wilson and McNabb 1983). Trace concentrations of secondary substrates may be transformed during the metabolism of primary substrate present at a higher concentration.

Factors present in the geochemical environment include the dissolved oxygen content, oxidation-reduction potential, temperature, pH, availability of other compounds and of nutrients, salinity, particulate matter, and presence of competing organisms (Kobayashi and Rittman 1982).

Studies using natural soil samples demonstrated that benzene could be mineralized (EPA 1979) and that toluene may be used as a cosubstrate during the aerobic, oxidative degradation of benzene. Ethylbenzene also biodegrades under aerobic conditions. Results of field experiments using in situ biodegradation columns installed in anaerobic, leachate-impacted aquifers at North Bay, Ontario, and

at Canada Forces Base Borden indicated that several aromatic hydrocarbons, including toluene, ethylbenzene, and 1,2,4-trimethylbenzene, also biodegrade under anaerobic conditions (Acton and Barker 1992).

TCE is degradable under anaerobic and aerobic conditions. The anaerobic pathway is one of reductive dechlorination; TCE is transformed to 1,1-DCE, *cis*- and/or *trans*-1,2-DCE, which may then be transformed to vinyl chloride (Kobayashi and Rittman 1982; Vogel and McCarty 1985). Aerobic degradation is thought to lead to the formation of carbon dioxide and nonvolatile products (Nelson and others 1986).

1.6.3 Contaminant Transport

This section presents a discussion of the mechanisms, rates, and impacts of contaminant transport via the air, surface water, and groundwater pathways at Plant 4. The following sections discuss the three transport pathways separately and include descriptions of the physical transport mechanisms associated with each pathway and an assessment of the impact that each pathway has on contaminant migration at Plant 4.

1.6.3.1 Contaminant Migration in Groundwater

As discussed in the Baseline Risk Assessment, the groundwater pathway poses the greatest risk, in terms of human health, of the contaminant pathways active at Plant 4. The physical mechanisms influencing the transport and fate of contaminants in groundwater at Plant 4 are discussed below.

Transport Mechanisms

There are three mechanisms of contaminant transport in groundwater: advection, mechanical dispersion, and molecular diffusion. Advection is the movement of solute by the bulk flow of groundwater, such that the component of contaminant transport can be described by the average velocity of groundwater. As discussed in Section 1.4.8.1, contaminant transport via advection occurs at a rate equal to the average linear velocity of the groundwater. In a uniform flow field (parallel flow lines), advective transport does not alter the size and shape of a particular plume. In a non-uniform flow field (converging or diverging flow lines), advective transport will likely alter plume geometries. For example, advective transport will cause plumes to spread laterally under conditions of diverging flow, possibly resulting in dilution of contaminant concentrations.

Advection is the dominant component of groundwater solute transport in most flow systems. Exceptions include flow systems that are characterized by extremely *small* flow velocities (i.e., low-gradient, massive clay formations) or extremely *variable* flow velocities (i.e., fractured rock formations). Because the upper-zone and Paluxy Aquifer flow systems are not characterized by these conditions, advection is expected to be the dominant means of groundwater contaminant transport at Plant 4.

Mechanical dispersion is the mixing process that occurs within a plume as a result of the complex nature of groundwater flow through porous media. Mechanical dispersion causes contaminant mass to spread laterally and thereby contributes to the dilution of contaminant plumes. The spreading is caused by the variability in groundwater velocities at the pore scale (because of grain roughness, path tortuosity, and pore-size variability) and at the macro-scale (because of small-scale heterogeneity).

Mechanical dispersion is proportional to the average linear velocity of groundwater and the concentration gradient for the contaminant. The coefficient of proportionality is termed the dispersivity, an empirical parameter. Dispersivity values are obtained from literature, tracer tests, or transport model calibration. Mechanical dispersion does contribute to the movement of contaminants in the Plant 4 groundwater system.

Molecular diffusion is the third mechanism of contaminant transport in groundwater. Molecular diffusion is the movement of solute in water resulting from the random motion of the solute particles and concentration gradients in the solution. Molecular diffusion generally leads to the dilution of contaminant plumes; however, the associated dilution is only significant in settings where groundwater velocities are very low. Molecular diffusion is not expected to be a significant transport mechanism in the Plant 4 groundwater system.

Effect on Plant 4 Contaminants

The results of the Baseline Risk Assessment indicate that the majority of the health risk associated with the RI/FS waste sites at Plant 4 is attributable to three groundwater contaminants. These contaminants are, in order of decreasing risk, TCE, 1,2-DCE (*cis*- and *trans*-isomers), and chromium(VI). The distribution of these and other groundwater contaminants is discussed in Section 1.5.5. The following discussion describes the transport of TCE, 1,2-DCE, and chromium(VI) in the upper-zone flow system, the Walnut Formation Aquitard, and the Paluxy Aquifer.

Contaminant Transport in the Upper-Zone Flow System The discussion presented in Section 1.5.5 describes three contaminant plumes within the upper-zone flow system: the East Parking Lot Plume, the West Plume, and the North Plume. Upper-zone contaminant transport within each of these plumes is discussed separately below. Each discussion addresses likely source areas, contaminant velocity estimates, contaminant discharge areas, travel times to discharge areas, and qualitative assessments of plume longevity.

The East Parking Lot Plume The East Parking Lot Plume is shown in Figures II-12 through II-18 of the RI. The plume contains varying concentrations of several contaminants. Concentrations of TCE are presented in Figures II-12 and II-13 of the RI. Concentrations of 1,2-DCE and chromium are presented in Figures II-14 and Figure II-18 of the RI, respectively.

The near-surface source areas for TCE, the most widespread compound in this plume, appear to be the south end of the Parts Plant (where large TCE vapor degreasers are used), Chrome Pit No. 3, and possibly Chrome Pits Nos. 1 and 2. TCE reaching groundwater in these source areas migrates primarily northeast beneath the East Parking Lot. The only possible exception to this migration trend occurs in the vicinity of Chrome Pit No. 3. As shown on the overlay map of groundwater elevation contours (see Figure II-24 of the RI), Chrome Pit No. 3 and the associated high TCE concentrations are located west of the groundwater divide in the vicinity of Building 12. It appears from this information that some TCE could be advected northwest from Chrome Pit No. 3 toward Meandering Road Creek. However, analytical results obtained during the RI and during previous investigations (see Figures II-12 and II-13 of the RI) show that significant northwesterly migration of TCE has not yet occurred in this area.

Comparison of 1989 and 1991 TCE concentrations (see Figures II-13 and II-12 of the RI, respectively) indicates that the distribution of TCE in the East Parking Lot Plume did not change

significantly over the 3 year period. This distribution appears to be the result of a combination of (1) nonaqueous-phase TCE flowing northeast along the base of the paleochannel beneath the East Parking Lot, and (2) aqueous-phase (dissolved) TCE advected east and southeast by the bulk movement of groundwater flowing beneath the East Parking Lot. This two-part transport process is illustrated in Figures II-12 and II-13 of the RI.

The migration of TCE as a nonaqueous phase is suggested by several features that are noted by Cohen and Mercer (1993) as being indicators of DNAPL. One of these indicator features is the presence of TCE in groundwater at concentrations that equal or exceed one percent of the solubility limit for TCE. For example, Figures II-12 and II-13 of the RI show a total of six different monitoring wells in the East Parking Lot with concentrations in excess of 10,000 $\mu\text{g/L}$ (solubility limit is approximately 1,100,000 $\mu\text{g/L}$). Jacobs (December 1992) also reported TCE values as high as 180,000 $\mu\text{g/L}$ in October of 1992 (well F-218). Another feature suggesting the migration of nonaqueous-phase TCE is the location of the very highly-contaminated monitoring wells. As shown in Figures II-12, II-13, and II-25 of the RI, all of the wells with TCE concentrations exceeding 10,000 $\mu\text{g/L}$ are located in the paleochannel that was eroded into the competent rock beneath the East Parking Lot. This distribution of TCE is consistent with the tendency for DNAPLS to migrate downslope along low-permeability rock or sediment strata. Lastly, the apparent migration of DNAPL seems to terminate in the vicinity of wells HM-82 and HM-94. In this area, there appears to be a shallow, localized depression in the competent bedrock (see lithologic logs for nearby borings in Appendices A-2 and K of the RI), and this depression is apparently acting as a collection point for DNAPL.

Taken together, the East Parking Lot TCE data suggest that a significant mass of nonaqueous-phase TCE has migrated from the Building 181/182 area to the northeast where the DNAPL migration apparently terminates in a shallow bedrock depression near wells HM-82 and HM-94. This DNAPL migration appears to be continuing as concentrations are again increasing in wells near Building 181 (Jacobs 1992d). This migration of nonaqueous-phase TCE has left and will continue to leave a distribution of residual DNAPL that is spread over the entire migration route. This residual DNAPL then acts as a subsurface source area for dissolved TCE that is subsequently advected to the east and southeast via groundwater flow (Figures II-12 and II-13 of the RI).

TCE concentrations for wells in the East Parking Lot and Building 181/182 areas are shown as a function of time in Figures 1-63 through 1-65. Figure 1-63 shows relatively high concentrations between 1,000 and 10,000 $\mu\text{g/L}$ up through 1990, when concentrations increase to as high as 820,000 $\mu\text{g/L}$ at F-218. The results suggest that the source area is slowly contributing contamination to the groundwater from residual DNAPL that is trapped in pore spaces by interfacial tension. The increase to 820,000 $\mu\text{g/L}$ at F-218 in 1993 indicates renewed DNAPL migration, which is most likely the result of an apparent TCE release discovered in June of 1991.

Figure 1-64 shows TCE concentrations up to 75,000 $\mu\text{g/L}$ for three wells located in or southeast of the paleo-channel. The concentrations in HM-88 and HM-89 are likely associated with residual DNAPL that was left in pore spaces during earlier migration of non-aqueous phase TCE along the paleo-channel. The increase after 1990 in concentrations at HM-088 indicate this well has been impacted by DNAPL migration following the 1990-1991 TCE release. The time series for HM-87 shows that this well is located in an area dominated by advective-dispersive transport of dissolved TCE which originated along the paleo-channel migration path of non-aqueous TCE.

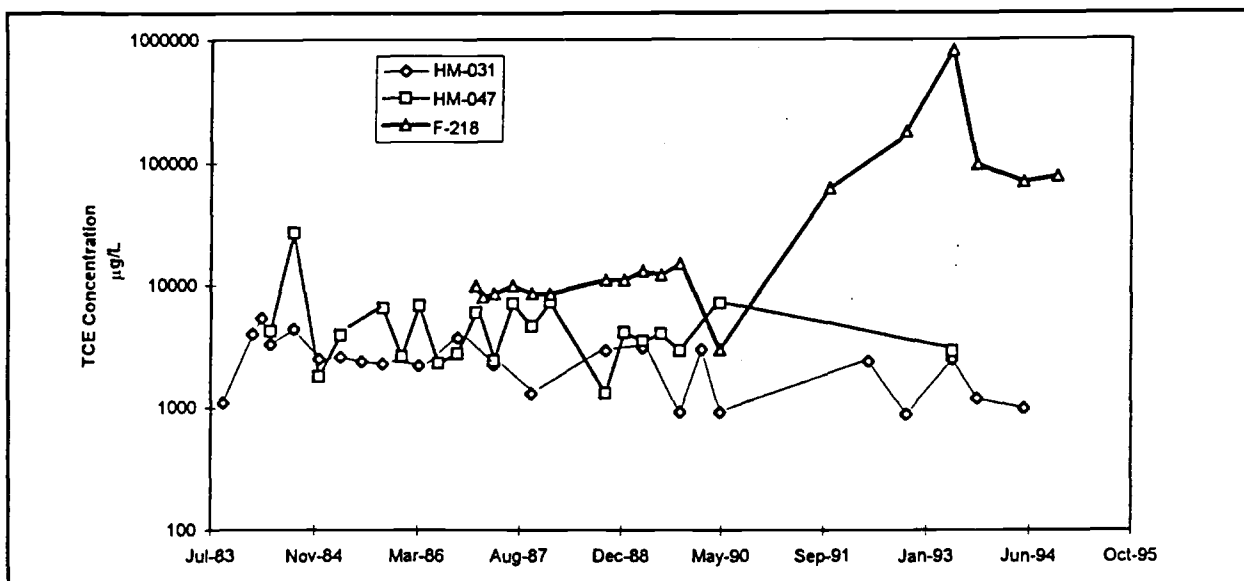


Figure 1-63. Chemical Time-Series for Upper-Zone TCE in Source Area of the East Parking Lot Plume

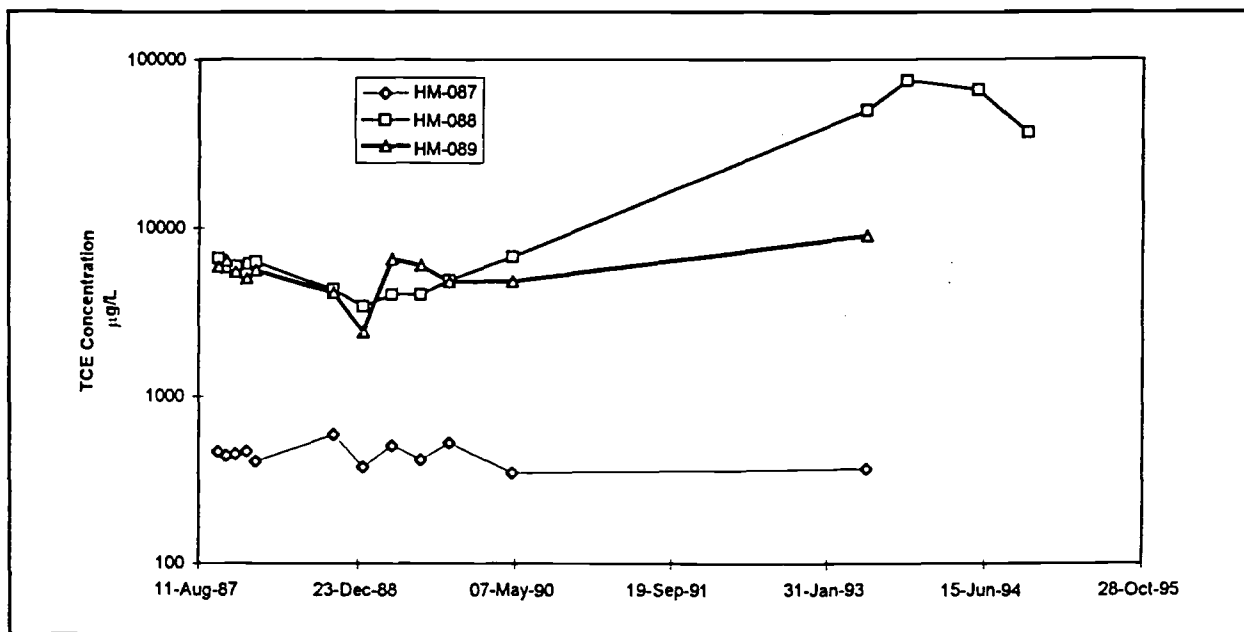


Figure 1-64. Chemical Time-Series for Upper-Zone TCE in the Central East Parking Lot Area

The temporal behavior of TCE concentrations in the vicinity of the window area is shown in Figure 1-65. At HM-94, located in the bedrock depression that defines the window area, concentrations are relatively high (indicative of DNAPL) and steady. This trend supports the hypothesis that DNAPL migration terminates and forms a subsurface pool in the bedrock depression. The DNAPL pool then acts as a new source area for dissolved TCE migration in the upper-zone and into the Paluxy Formation. At HM-86, located 450 feet south of HM-94, the Walnut Formation is

thicker (6 feet) and extends to a higher elevation. Figure 1-65 shows that concentrations at HM-86 are slowly decreasing after an increase in late 1986. This trend suggests that the source for TCE in this part of the plume is residual DNAPL left in the paleochannel during earlier migration of a DNAPL slug. The declining trend should continue until DNAPL currently in the vicinity of F-218 reaches the northeast end of the paleochannel that is situated upgradient of HM-86.

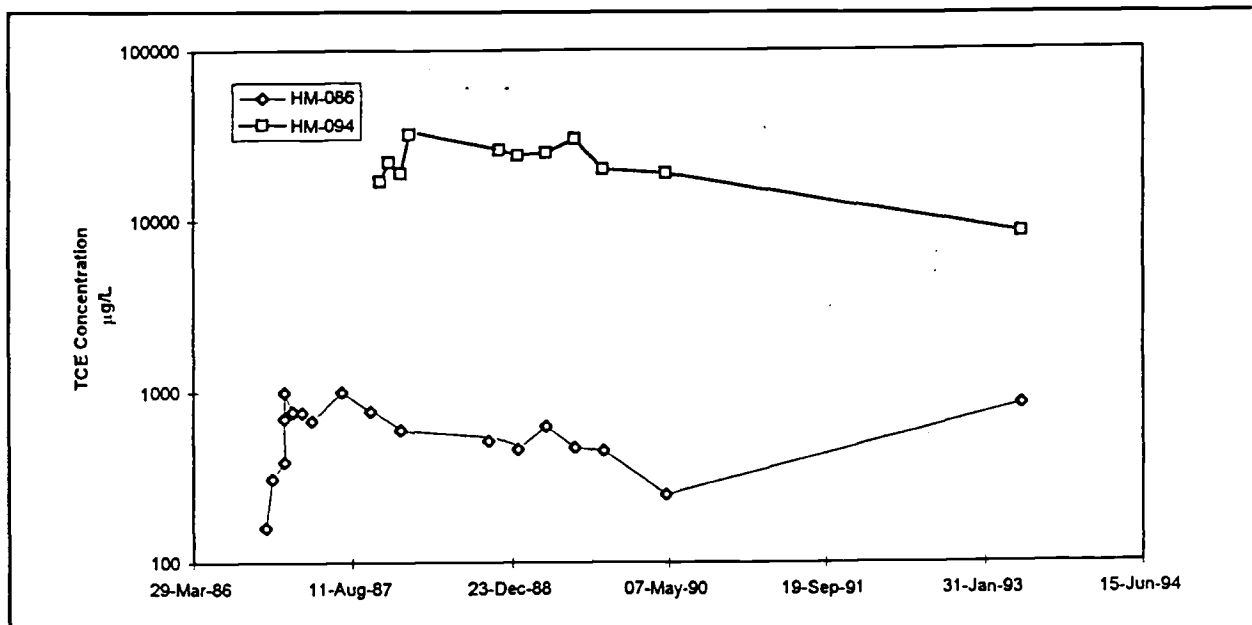


Figure 1-65. Chemical Time-Series for Upper-Zone TCE in the Vicinity of the Window Area

The low concentrations at HM-86 may also reflect low permeability deposits in this area which tend to deflect and slow the migration of TCE-laden water migrating from the suspected DNAPL zone.

Examination of the northern extent of the East Parking Lot Plume (see Figures II-12 and II-13 of the RI) and the overlay map of groundwater elevation contours (see Figure II-24 of the RI) reveals that TCE is found in wells that are not located along flow lines originating in the apparent source areas. Examples include wells HM-117, HM-118, HM-119, and HM-121. Contamination in these wells could have originated at the apparent source areas only if (1) local groundwater flow directions differ from those indicated in the groundwater elevation contour map or (2) cross-gradient transport has occurred as a result of mechanical dispersion. The configuration of the bedrock surface shown in Figure II-24 of the RI suggests that a limb of the bedrock channel may extend in a northeasterly direction from the window area toward well HM-121. Preferential flow would be expected along this limb of the channel because higher transmissivities are expected within the channel limb than in the surrounding bedrock. However, evaluation of local groundwater flow directions and refinement of bedrock contours require more resolution than existing data will allow. The second possibility listed above, cross-gradient transport resulting from mechanical dispersion, is considered unlikely because the magnitude of cross-gradient transport required to achieve the observed distribution would have to exceed the downgradient advective and the dispersive transport.

The most likely explanation for the TCE contamination identified in the northern portion of the East Parking Lot Plume is that it originated at FDTA-2 in the West Plume. Figures II-12 and II-13 of the RI show high concentrations of TCE at F-211, HM-29, and HM-51. These wells define a southeast-

trending, high-concentration lobe of the West Plume TCE distribution. Examination of Figure II-25 of the RI and Figure 1-8a show that the high-concentration lobe defined by these three wells overlies a shallow, east-trending channel in the competent bedrock. As shown by Figure 1-8b, the bedrock channel dips in a direction that is opposite the direction of groundwater flow. This combination of hydrogeology and contaminant distribution again suggests the possibility of DNAPL migration. If nonaqueous phase TCE has migrated southeastward in the shallow bedrock channel, it would have passed beneath the groundwater divide that forms the boundary between the East Parking Lot Plume and the West Plume. Once east of this flow divide, dissolved TCE would migrate east and contribute to the formation of the northern portion of the East Parking Lot Plume. This hypothesis is supported by the "non-detects" obtained for TCE at HM-57, HM-93, and W-152 (Figures II-12 and II-13 of the RI); these three wells are located between the migration pathways originating at the Building 181/182 and FDTA-2 source areas.

As shown in Figure II-13b of the RI, the downgradient extent of the East Parking Lot Plume extends onto CAFB. It is apparent from this figure that TCE source areas are located on CAFB near the north apron, Landfill 6 north of Farmers Branch Creek, and Landfills 4 and 5.

The compound 1,2-DCE is the second most common contaminant found in the East Parking Lot Plume (see Figure II-14 of the RI). The distribution of 1,2-DCE and the absence of a clearly defined, high-concentration area suggest that 1,2-DCE has not originated from a localized above-ground source area. Rather, it appears likely that the distribution of 1,2-DCE has resulted largely from the biodegradation of TCE.

The most probable source areas for chromium found in the East Parking Lot Plume are Chrome Pits Nos. 1, 2, and 3 (see Figure II-18 of the RI). Although the data were reported as total chromium, it is assumed that the majority of the dissolved chromium in the groundwater is hexavalent chromium [chromium(VI)] because chromium(VI) compounds, such as chromic acid used in electroplating processes, are highly soluble in water (solubility of Chromate [CrO_3] in cold water is 617 mg/cm^3 [CRC Press, Inc. 1990]).

Contaminant velocities in the East Parking Lot Plume are governed largely by the average linear velocities of upper-zone groundwater. As shown in Table 1-7, estimates of average linear velocities in the upper-zone flow system range from 0.05 to 0.11 foot per day. Higher velocities and, therefore, more rapid advection of contaminants within the plume, are anticipated in areas that contain significant gravel deposits such as the East Parking Lot paleochannel.

Because of the tendency for organic compounds to adsorb onto solid particles (see Section 1.6.2.2), the actual contaminant velocities of TCE and 1,2-DCE are less than the groundwater velocities. Under adsorption conditions, the average contaminant velocity, \bar{v}_c , is given by Equation 1-6. As noted in Section 1.6.2.2 (see Equation 1-7), defendable estimates of the distribution coefficient, K_d , were not obtained from soil and groundwater analytical results. However, estimates of contaminant retardation as a result of adsorption can be obtained using parameter estimates from published data. The distribution coefficient is estimated from Equation 1-4. On the basis of the following estimates for parameters in Equations 1-4 and 1-6, the retardation coefficients, R , for TCE and 1,2-DCE are approximately 13 and 6, respectively:

- Bulk density: $\rho_b = 1.86 \text{ g/cm}^3$ (Freeze and Cherry 1979, Equation 8.26)
- Porosity: $n = 0.3$ (dimensionless) (Section 1.4.8)
- Organic carbon content: $f_{oc} = 0.017$ (dimensionless) (Mercer 1988; Jury and others 1983)

- Organic carbon-water partition coefficient for TCE: $K_{oc} = 126 \text{ mL/g}$ (EPA 1986, *Superfund Public Health Evaluation Manual*)
- Organic carbon-water partition coefficient for *cis*-1,2-DCE: $K_{oc} = 49 \text{ mL/g}$ (EPA 1986)
- Organic carbon-water partition coefficient for *trans*-1,2-DCE: $K_{oc} = 59 \text{ mL/g}$ (EPA 1986)

Because the *cis* isomer of DCE is more prevalent than the *trans* isomer, the retardation coefficient was based on the organic carbon-water partition coefficient, K_{oc} , value for *cis*-1,2-DCE, leading to a conservative estimate for overall retardation of 1,2-DCE.

The estimates for TCE and 1,2-DCE contaminant velocities, shown in Table 1-117, are derived by scaling the average linear groundwater velocities (see Table 1-7) by their respective retardation coefficients.

Table 1-117. Estimates of Retarded Contaminant Velocities for TCE and 1,2-DCE in the East Parking Lot Plume

Compound	Minimum Average Linear Velocity (feet per day)	Maximum Average Linear Velocity (feet per day)	Retardation Coefficient (R)	Minimum Retarded Velocity (feet per day)	Maximum Retarded Velocity (feet per day)
TCE	0.05	0.17	14	0.004	0.01
1,2-DCE	0.05	0.17	6	0.008	0.03

The estimates shown in Table 1-117 suggest that 1,2-DCE is more readily transported by the flowing groundwater than TCE. However, it appears that contaminant velocities obtained from this simple analysis are too low to account for the axial length of the East Parking Lot Plume. For example, the total migration distance for contaminants transported from near Building 182 to the window area and then south to the Landfill No. 5 area is in excess of 7,000 feet. If migration is assumed to have begun in 1940 and continued for the subsequent 50 years, the average contaminant velocity would be in excess of 7,000 feet per 50 years, or 0.4 feet per day. This estimate exceeds the maximum retarded velocity estimate shown in Table 1-117 (0.03 ft/d) by a factor greater than 13.

The discrepancy observed in contaminant velocity is most likely the result of two factors. The first concerns the high TCE concentrations reported in the paleochannel area, which suggest the presence of DNAPL. If TCE is present in this channel as pure-phase product, then the past migration of this product would have been governed by the topography of the paleochannel (relatively steep as shown in Figure II-25 of the RI) and the high intrinsic permeability of the basal sediments (mostly gravel). This combination of steep bedrock slopes and high intrinsic permeability could produce high DNAPL migration rates in the vicinity of the paleochannel and the window area.

The second factor concerns the maximum average linear velocity calculated on the basis of the logarithmic mean of the hydraulic conductivity, K (see Table 1-7). The logarithmic mean K does not account for the relatively large but localized areas of basal gravel deposits in which higher K values are expected. The discrepancy in contaminant velocity estimates described above suggests that the localized gravel deposits have played a significant role in the evolution of the East Parking Lot Plume. The impact of localized heterogeneity on flow and transport are being addressed in the site-scale modeling of the flow system.

For chromium(VI), retardation from adsorption is minimal because of the high solubility of this ion. The transport velocity for chromium is, therefore, approximately equal to the average linear velocity of the groundwater. However, Figure II-18 of the RI shows that the extent of chromium in the East Parking Lot Plume is not equal to that of TCE or 1,2-DCE. This is most likely because chromium transport occurs at rates nearly equal to the average linear velocity of the groundwater, while TCE transport appears to have been accelerated as a result of DNAPL flow along the axis of the paleochannel. It is also possible that chromium(VI) was introduced to the groundwater system after the introduction of TCE.

The ultimate discharge point for the East Parking Lot Plume is the West Fork of the Trinity River. However, the downgradient extent of the plume has not been defined. Consequently, the travel time required for the plume to reach the river cannot be accurately predicted. Using the contaminant velocity of 0.4 feet per day obtained above, the travel time from well CAFB-LF05-19 to the West Fork of the Trinity River is approximately 40 years. The time required for the plume to reach the river will likely be less than 40 years because the plume is known to extend beyond well CAFB-LF05-19.

The West Plume The West Plume is shown in Figures II-12 through II-18 of the RI. TCE concentrations are presented in Figures II-12 and II-13 of the RI; concentrations of 1,2-DCE and chromium are presented in Figures II-14 and II-18 of the RI, respectively.

There are five source areas that appear to be contributing to groundwater contamination in the West Plume. These source areas and the contaminants they are likely contributing are as follows:

- FDTA-2: chlorinated solvents, VOCs, and chromium
- Landfill No. 1: chlorinated solvents, VOCs, semi-VOCs, and possibly chromium
- Landfill No. 3: chlorinated solvents, VOCs, semi-VOCs, and possibly chromium
- FSA-1: VOCs
- Tank 19: 2-butanone, and possibly VOCs and semi-VOCs

The most contaminated sections of the West Plume are associated with two of the source areas, the central portion of Landfill No. 3 and FDTA-2 (see Figures II-12, II-13, and II-14 of the RI).

In Landfill No. 3, DNAPL was detected in wells F-214, HM-38, and W-130. All three of these wells are located in a small depression or channel incised into the Walnut Formation (see Figure II-25 of the RI). This depression apparently serves as a collection point for TCE that may have been disposed in the landfill. A sample of DNAPL was collected from well F-214 in the spring of 1991. Results of a qualitative analysis performed on the sample indicated that the DNAPL layer in well F-214, which has been reported to be as much as 3-feet thick, consists of 64 percent TCE, 23 percent toluene, and smaller percentages of several other VOCs.

In the vicinity of FDTA-2, TCE concentrations as high as 340,000 $\mu\text{g/L}$ (Hargis + Associates 1989d) have been reported at well HM-51. The magnitude of these concentrations indicates that TCE is likely present as pure product. TCE concentrations on the order of thousands of micrograms per liter are also found in an elongate area extending southeast of HM-51 to F-211 and HM-29 (see Figures II-12 and II-13 of the RI and Hargis + Associates 1989d).

The compound 1,2-DCE has been detected at concentrations of 69,000 and 80,000 $\mu\text{g/L}$ in wells HM-21 and HM-51, respectively, suggesting that solvent-grade 1,2-DCE may have been burned at FDTA-2 and disposed in Landfill No. 3. Lower concentrations of 1,2-DCE, found throughout the rest of the plume, are most likely the result of TCE degradation.

Chromium has been found at concentrations below 50 $\mu\text{g/L}$ throughout much of the West Plume (see Figure II-18 of the RI and Hargis + Associates 1989b). However, chromium concentrations of 50, 151, and 105 $\mu\text{g/L}$ have been reported at wells HM-20, F-215, and HM-29, respectively. These higher concentrations are not readily associated with any known waste site but coincide with the location of elevated TCE concentrations extending southeast of HM-51 and FDTA-2. This correlation is discussed below.

The direction of groundwater transport of dissolved contaminants in the West Plume is predominantly to the west and southwest (see Figure II-24 of the RI). Although the hydraulic gradient is relatively small over much of the plume (evidenced by the lack of contour lines), the westerly flow direction was confirmed by contouring water-level elevations at a 2-foot contour interval. Spot checking of individual groundwater elevations (see Appendix D-1 of the RI) also confirms the westerly flow direction.

Given the presence of westerly groundwater flow and transport, and the observation that FDTA-2 is a likely source for TCE contamination, the apparent southeasterly migration of TCE from FDTA-2 (see Figures II-12 and II-13 of the RI) appears anomalous. One explanation for this apparent anomaly is provided by Figure II-25 of the RI, which shows a bedrock depression or trough extending southeast and east of FDTA-2. As noted above, the high TCE concentrations at HM-51 indicate that DNAPL TCE entered the upper-zone flow system in the FDTA-2 area. After reaching the bedrock surface, this DNAPL has apparently flowed into the bedrock channel, moving in a southeasterly direction relative to FDTA-2. Along this migration route, residual DNAPL left at the base of the upper-zone flow system contributes dissolved TCE to the overlying groundwater, resulting in the contaminant distribution shown in Figures II-12 and II-13 of the RI. The lower concentrations of TCE found in downgradient portions of the West Plume can be explained by westerly and southwesterly advection of TCE that was derived from the elongate DNAPL migration path.

This two-component migration hypothesis for TCE originating at FDTA-2 is supported by the chemical time-series graphs shown in Figures 1-66 and 1-67. In the immediate vicinity of the source area, concentrations are very high at HM-51 (Figure 1-66). In HM-029 and F-215, located near the bedrock channel that dips southeastward from FDTA-2, TCE levels are moderately high and steady, suggesting the presence of small amounts of DNAPL derived from non-aqueous phase migration along the channel axis. Downgradient from the elongate area defined by the paleochannel (Figure II-25 of the RI), wells F-207, -216, and -217 show moderate to low TCE levels that are generally decreasing with time (Figure 1-67). These concentrations and the trends they display indicate that dissolved TCE in this portion of the plume is derived from residual non-aqueous TCE in the paleochannel. It is also possible that TCE in wells such as F-216 and F-217 is derived from wastes in Landfill No. 1, although the most contaminated portions of this landfill were excavated in 1986 (see Section 1.5.3.3.). The slight increase in concentrations at the end of the time series for F-216 and F-217 may reflect changes in sampling and analysis procedures between 1990 and 1993.

Because of the small hydraulic gradients and the east-trending bedrock channel near the upgradient limit of the West Plume, it is also possible that TCE originating at FDTA-2 could have migrated beneath the Assembly Building. Hydraulic gradients and bedrock topography would then act to move this contamination in a northeasterly direction toward the north end of the runway.

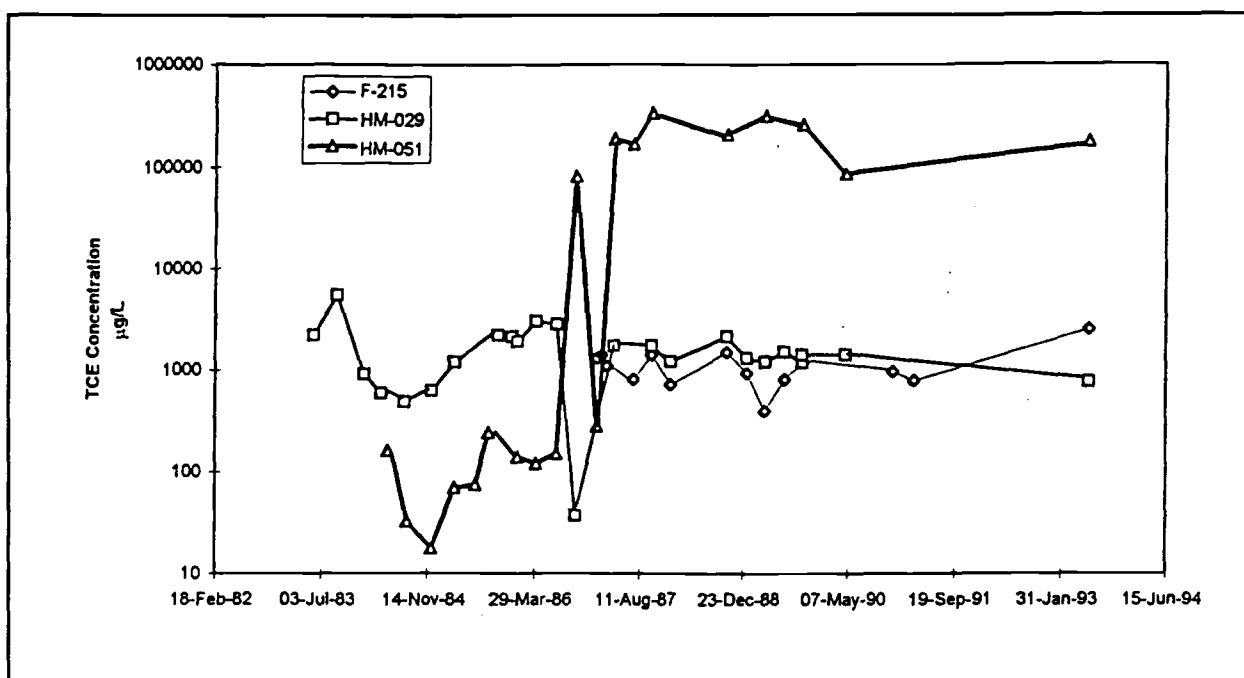


Figure 1-66. Chemical Time-Series for Upper-Zone TCE in the Vicinity of FDTA-2 and the Nearby Bedrock Channel

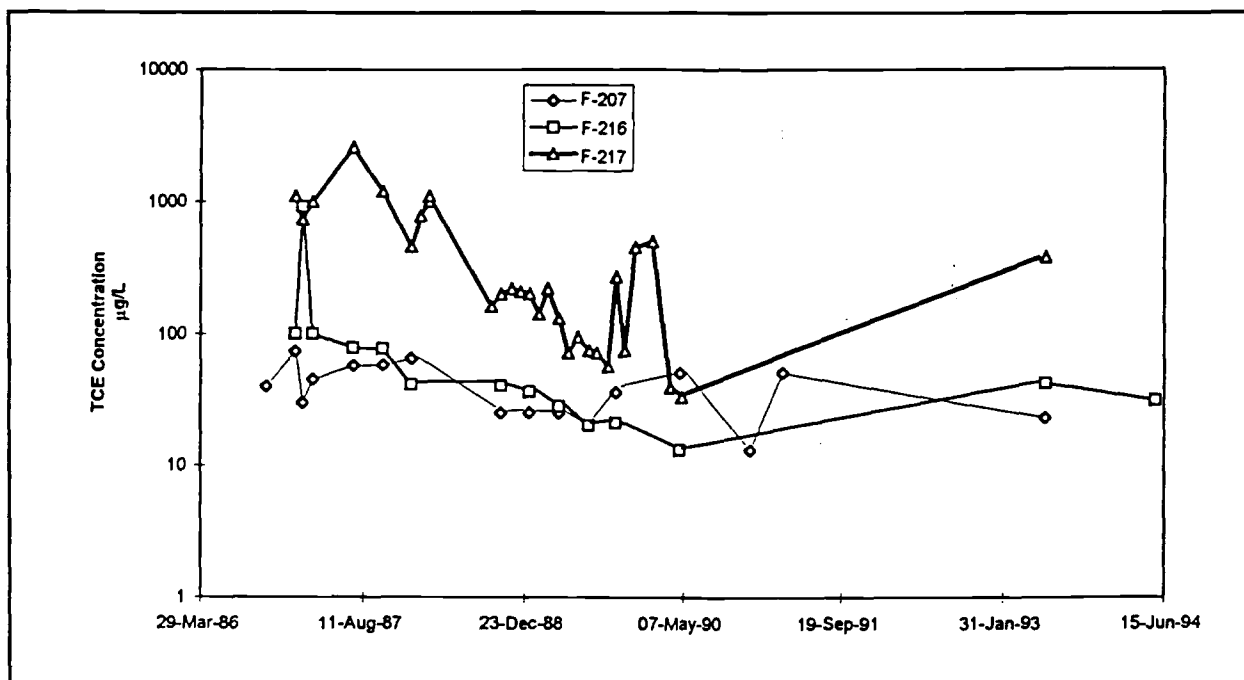


Figure 1-67. Chemical Time-Series for Upper-Zone TCE Downgradient from the FDTA-2 Paleochannel

The southeasterly migration of DNAPL TCE from FDTA-2 also provides a possible explanation for the elevated chromium found in the vicinity of well F-215. If production activities at Plant 4 included processes in which chromium-plated parts came into contact with TCE (during vapor degreasing, for instance), then the TCE disposed at FDTA-2 would likely have contained chromium. As DNAPL TCE migrates southeast from FDTA-2, the chromium will migrate with the TCE until sufficient mixing has occurred to allow the chromium to dissolve into the overlying groundwater. Advection to the west and southwest would then lead to the low concentrations found in the downgradient areas of the West Plume.

Contaminant velocities within the West Plume for the dissolved phases of TCE, 1,2-DCE, and chromium are tabulated in Table 1-118. For TCE and 1,2-DCE, retarded contaminant velocities were calculated from Equation 1-6, Table 1-7, and retardation coefficients calculated above. For chromium, the contaminant velocity shown is equal to the average linear velocity. This is based on the assumption noted earlier that chromium in the groundwater is in the hexavalent form, which is relatively soluble and not subject to significant sorptive retardation (i.e., $R = 1$).

Table 1-118. Estimates of Retarded Contaminant Velocities for TCE and DCE in the West Plume

Compound	Minimum Average Linear Velocity (feet per day)	Maximum Average Linear Velocity (feet per day)	Retardation Coefficient (R)	Minimum Retarded Velocity (feet per day)	Maximum Retarded Velocity (feet per day)
TCE	0.09	6.77	14	0.006	0.48
1,2-DCE	0.09	6.77	6	0.015	1.13
Chromium	0.09	6.77	1	0.09	6.77

Maximum contaminant velocities occur in the small channel near well F-214 where hydraulic gradients are as high as 0.2 ft/ft. This steeply sloping section of the upper-zone flow system is clearly evident in Figure II-24 of the RI. The steep hydraulic gradients occur in the channel incised into the Walnut Formation near Meandering Road Creek (see Figures 1-20, 1-21, and II-25 of the RI). Minimum contaminant velocities in the West Plume occur in the area just north and west of Building 14 where hydraulic gradients are relatively low.

During the RI/FS field investigations, seeps along Meandering Road Creek were observed at several locations along the west boundary of Landfill No. 3. These seeps are discharge points for upper-zone groundwater. The most significant discharge point, in terms of contaminant transport, is located near well F-214. A Walnut Formation bedrock high, extending north-south between Meandering Road Creek and Plant 4, impedes much of the groundwater flow to the creek. However, in the vicinity of well F-214, a channel incised into the bedrock has removed most of the Walnut Formation. Historical aerial photographs reveal that the channel was forming as an incipient tributary to the creek. The channel was later filled with construction rubble after manufacturing activities began at Plant 4. The areal plan views and cross-sectional views shown in Figures 1-20, 1-21, and II-25 of the RI illustrate the capacity of the channel to act as a major point of groundwater discharge for the West Plume.

The North Plume The North Plume is shown in Figures II-12 through II-18 of the RI. As shown in Figures II-12 and II-13 of the RI, TCE was detected in only one well (F-209). The source for the isolated occurrence of TCE is not known. TCE-degradation products and chromium were not detected in any of the North Plume wells.

Several wells in the North Plume area were found to contain LNAPL. Samples of the LNAPL were collected and submitted for qualitative analysis. Results of those analyses indicated that jet fuel, tentatively identified as JP-4, was the most commonly occurring substance. The likely source for this contamination is a fuel spill. Groundwater samples were not collected from the wells containing LNAPL; therefore, the impact of the spilled fuel on groundwater quality cannot be assessed at these wells. However, groundwater samples were collected from a number of wells both upgradient and downgradient of the apparent fuel spill area. The reported VOC concentrations exceeding CRQLs in these wells are shown in Figure II-15 of the RI. Of the wells sampled, only well F-209 contained significant groundwater contamination, which is most likely attributed to the LNAPL that was formerly detected in this well (Hargis + Associates 1988b).

Surface water sample locations SW-10, SW-11 (groundwater discharge seeps), and Outfall No. 3 are also shown in Figure II-15 of the RI. As discussed in Section 1.4.6, samples from these locations were found to be virtually free of VOC contamination. These sample points are located downgradient from FSA-3 where discharge of upper-zone groundwater occurs (see Figure II-24 of the RI).

The analytical and field data for the North Plume area indicate that even in the presence of a significant fuel-related LNAPL plume, dissolved contaminant migration of compounds such as BTEX has been minimal. The lack of dissolved contaminant migration may be attributed to two factors. First, hydraulic gradients in the North Plume area are relatively flat, resulting in low advective groundwater velocities (see Figure II-24 of the RI and Table 1-7). Secondly, low contaminant velocities are anticipated because significant adsorptive retardation is associated with BTEX compounds. For example, K_{oc} values for BTEX compounds range from 132 to 1,830. For comparison, the K_{oc} for TCE is 126. The associated retardation factors and contaminant velocity estimates for the BTEX components of fuel are shown in Table 1-119 (on the basis of average linear velocity estimates from Table 1-7).

Table 1-119. Estimates of Retarded Contaminant Velocities for BTEX Compounds in the North Plume

Compound	Minimum Average Linear Velocity (feet per day)	Maximum Average Linear Velocity (feet per day)	Retardation Coefficient (R)	Minimum Retarded Velocity (feet per day)	Maximum Retarded Velocity (feet per day)
Benzene	0.05	0.23	15	0.003	0.02
Ethylbenzene	0.05	0.23	150	0.0003	0.002
Toluene	0.05	0.23	58	0.0009	0.002
Xylenes	0.05	0.23	194	0.0002	0.001

The migration of dissolved fuel compounds derived from FSA-3 is not expected to be significant because of these low contaminant velocity estimates. Those contaminants that do migrate will

ultimately be discharged via seeps located north and west of the North Plume area. Seeps at SW-10 and SW-11 are two examples of such discharge points. It is likely that additional groundwater seeps, concealed by vegetation, are present in the area northwest of the North Plume, particularly where the ground surface slopes toward Lake Worth.

Contaminant Transport Through the Walnut Formation Aquitard Contaminant transport through the Walnut Formation Aquitard is likely occurring in two locations at Plant 4. These locations are the window area and the lower reaches of Meandering Road Creek. In both of these areas, the Walnut Formation has been extensively eroded and is thin or absent. Low concentrations of organic contaminants commonly found in upper-zone groundwater and Meandering Road Creek, such as TCE, 1,2-DCE, and vinyl chloride, have been detected in Paluxy Formation groundwater in both of these areas. The presence of these compounds in the Paluxy Aquifer suggests the hypothesis that migration through the Walnut Formation is occurring in these areas. Alternatively, one or both of the Paluxy Aquifer monitoring wells in LF-3 (P-22U and P-22M) may be providing a conduit across the Walnut Formation. This situation could have resulted from completion difficulties such as sloughing, or from the drillers lack of adherence to design specifications.

In Section 1.4.8.2, the volumetric flux through the window area was estimated using hydraulic head data in upper-zone and Paluxy Formation monitoring wells. This flux estimate, between 0.54 and 54 ft³/day, can be combined with the Walnut Formation retardation coefficient and the average TCE concentration for upper-zone groundwater in the window area (20,000 µg/L) to provide an estimate of TCE flux through the window area and into the Paluxy Formation. Assuming the Walnut Formation has a bulk density of 1.9 g/cm³, a porosity of 0.075 (Advanced Terra Testing, Inc. 1991), and a fraction organic-carbon content of 0.012 (Huffman Laboratories, Inc. 1991), Equations 1-4 and 1-6 result in an R value of 40. Scaling the volumetric flux estimates by an R value of 40 and multiplying by the average TCE concentration of 20,000 µg/L results in a mass flux estimate between 0.0003 and 0.03 ounces per day (0.008 to 0.8 g/d). If retardation is not occurring due to a lack of organic carbon or exhaustion of sorption sites, the contaminant mass flux estimates are 0.011 to 1.1 oz/day (0.30 to 30 g/d).

The relative accuracy of the window area contaminant mass flux estimate can be checked by estimating the contaminant mass within the Paluxy Formation. Because the majority of the contaminant mass is in the Paluxy upper sand, the estimate will be computed only for the upper sand. From Figures II-19a and II-19c of the RI, the area of the plume was estimated as:

$$\begin{aligned}\text{Area within 1000ppb contour} &= 2,260,000 \text{ ft}^2 \\ \text{Area between 1000ppb and 100ppb contour} &= 1,459,000 \text{ ft}^2\end{aligned}$$

Assuming a seven-foot saturated thickness and a porosity of 0.3 for the upper sand, the mass of TCE within these two contours is computed as follows (incremental area between 1000 and 100 ppb contour assigned median value of 550 ppb):

$$\begin{aligned}\text{Mass within 1000ppb contour} &= 1000 \text{ } \mu\text{g/L} * \text{Volume} \\ \text{Volume} &= 2,260,000 \text{ ft}^2 * 7 \text{ ft} * 0.30 = 4,746,000 \text{ ft}^3 \\ &= 134,407,000 \text{ L} \\ \text{Mass} &= 1000 \text{ } \mu\text{g/L} * 134,407,000 \text{ L} = 134\text{E}09 \text{ } \mu\text{g} = 134,400 \text{ g}\end{aligned}$$

$$\begin{aligned}
 \text{Mass between 1000 and 100 ppb contour} &= 550 \mu\text{g/L} * \text{Volume} \\
 \text{Volume} &= 1,459,000 \text{ ft}^2 * 7 \text{ ft} * 0.30 = 3,063,900 \text{ ft}^3 \\
 &= 86,770,000 \text{ L} \\
 \text{Mass} &= 550 \mu\text{g/L} * 86,770,000 \text{ L} = 477\text{E}08 \mu\text{g} = 47,720 \text{ g}
 \end{aligned}$$

$$\text{Total TCE mass in upper sand} = 134,400 \text{ g} + 47,720 \text{ g} = 182,120 \text{ g}$$

Assuming 20,000 $\mu\text{g/L}$ for the average upper zone TCE concentration in the window area, and ignoring retardation, the contaminant mass flux rate from the upper zone to the upper sand is

$$\begin{aligned}
 \text{Mass flux} &= 20,000 \mu\text{g/L} * 54 \text{ ft}^3/\text{d} * 28.32 \text{ L}/\text{ft}^3 = 30.6\text{E}06 \mu\text{g}/\text{d} = 30.6 \text{ g}/\text{d} \\
 &= 11,000 \text{ g}/\text{yr}
 \end{aligned}$$

Given 182,120 g as an estimate of the total TCE mass *in* the upper sand, and 11,170 g/yr as an estimate of the contaminant mass flux rate *into* the upper sand, an estimate of the duration of this flux is $(182,120 \text{ g}) / (11,000 \text{ g}/\text{yr}) = 16 \text{ yrs}$. Assuming that TCE release into the subsurface likely began shortly after the plant was built, and leakage into the upper sand likely began not long afterward, the 16 year estimate for the duration of TCE flux into the upper sand is recognized as too short. This can be explained by the realization that migration of TCE through the window area Walnut Formation would likely have begun at a rate considerably smaller than the current or maximum rate estimated above. Stated another way, 11,000 g/yr is a conservatively large estimate for the average TCE mass flux rate into the upper sand. TCE flux into the upper sand is certain to have begun at a slower rate, likely in the 1950's or 1960's, and increased to a rate less than or equal to 11,000 g/yr. The mass balance calculation above provides a means of testing the retardation factor of 40 estimated previously. If $R = 40$ accurately quantifies the retardation process and if that process has been occurring continuously over the duration of TCE migration through the window area Walnut Formation, the annual mass flux rate would be 275 g/d and the duration of the flux needed to contribute 182,120 g of TCE to the upper sand would be 640 years. Clearly, $R = 40$ overestimates the average retardation process, most likely due to lower-than-estimated organic carbon content or exhaustion of sorption sites during the later years of leakage through the window area. On the basis of this reasoning, 30.6 g/d (1.1 oz/d) will be considered to provide a reasonable upper bound to the rate of TCE migration into the upper sand.

To provide a basis for estimating cleanup levels in the Upper Zone above the window area that will not result in excessive degradation of the Paluxy Aquifer, the 30.6 g/d mass flux can be used in a simple mixing or dilution model. This calculation provides a means of relating Upper Zone discharge in the window area to Paluxy aquifer water quality after flowing beneath the upper sand TCE plume (Figures II-19a and II-19c of the RI). The mixing model is based on the following equation:

$$Q_{UZ}C_{UZ} + Q_{P,INFLOW}C_{P,INFLOW} = (Q_{P,OUTFLOW})C_{P,OUTFLOW}$$

where,

$$\begin{aligned}
 Q_{UZ} &= \text{volumetric flux through Walnut Formation in window area (54ft}^3/\text{d),} \\
 C_{UZ} &= \text{TCE concentration for upper zone in window area (20,000}\mu\text{g/L),} \\
 Q_{P,INFLOW} &= \text{volumetric flux for water in Paluxy Aquifer flowing into zone beneath} \\
 &\quad \text{upper sand TCE plume,} \\
 C_{P,INFLOW} &= \text{TCE concentration for water in Paluxy Aquifer prior to flowing} \\
 &\quad \text{beneath upper sand TCE plume (0 }\mu\text{g/L),}
 \end{aligned}$$

$$Q_{P,OUTFLOW} = \text{volumetric flux for water in Paluxy Aquifer flowing out from zone beneath upper sand TCE plume } (= Q_{UZ} + Q_{P,INFLOW}),$$

$$C_{P,OUTFLOW} = \text{TCE concentration for water in Paluxy Aquifer prior to flowing beneath upper sand TCE plume.}$$

This model is based on the assumption that the Paluxy upper sand provides no permanent storage of water or contaminant mass: every thing that drains into the upper sand ultimately drains out. This assumption is reasonable given the perched setting of the upper sand relative to the Paluxy Aquifer (Figure 1-68). It is also conservative, given that *some* contaminant mass undoubtedly will sorb onto the solid phase within the upper sand. For the model shown in Figure 1-68, all of the contaminant mass discharged into and mixed with groundwater in the Paluxy Aquifer. The Paluxy aquifer flux, Q_P , with which the upper zone flux, Q_{UZ} , mixes is illustrated in Figure 1-69.

The width of the inflow face, 2000 ft is the width of the upper sand TCE plume measured orthogonal to the Paluxy Aquifer hydraulic gradient. The height of the inflow face, 20 ft, is based on the assumption that mixing occurs over the uppermost 20 ft of saturated thickness within the aquifer as water is drawn to a water supply well screened in the top 20 ft of the aquifer. Using the Paluxy Aquifer hydraulic conductivity of 0.006 cm/s (17 ft/d) and the average gradient of 0.0065 (dimensionless) from Section 3.8, $Q_{P,INFLOW}$ can be calculated from

$$Q_{P,INFLOW} = K * dh/dx * A$$

where

$$\begin{aligned} A &= \text{cross-sectional area orthogonal to flow} \\ &= 20 \text{ ft} * 2000 \text{ ft} \\ &= 40,000 \text{ ft}^2 \end{aligned}$$

giving

$$\begin{aligned} Q_{P,INFLOW} &= 17 \text{ ft/d} * 0.0065 * 40,000 \\ &= 4422 \text{ ft}^3/\text{d} \end{aligned}$$

Substituting this into the mixing equation and solving for $C_{P,OUTFLOW}$ gives

$$\begin{aligned} C_{P,OUTFLOW} &= ((54 \text{ ft}^3/\text{d} * 20,000 \mu\text{g/L}) + (4422 \text{ ft}^3/\text{d} * 0)) / (54 \text{ ft}^3/\text{d} + 4422 \text{ ft}^3/\text{d}) \\ &= 241 \mu\text{g/L} \end{aligned}$$

This result shows that if TCE contamination from the upper zone is allowed to continue migrating unabated through the window area, TCE concentrations in the Paluxy Aquifer can be expected to reach as high as 240 $\mu\text{g/L}$. Assuming the upper zone is to be remediated to an extent such that window area discharge does not cause TCE concentrations ($C_{P,OUTFLOW}$) in the Paluxy Aquifer to exceed the MCL of 5 $\mu\text{g/L}$, the mixing equation can be solved in reverse to estimate the required target concentration for the upper zone:

$$\begin{aligned} C_{UZ} &= (54 \text{ ft}^3/\text{d} + 4422 \text{ ft}^3/\text{d}) * 5 \mu\text{g/L} / 54 \text{ ft}^3/\text{d} \\ &= 414 \mu\text{g/L} \end{aligned}$$

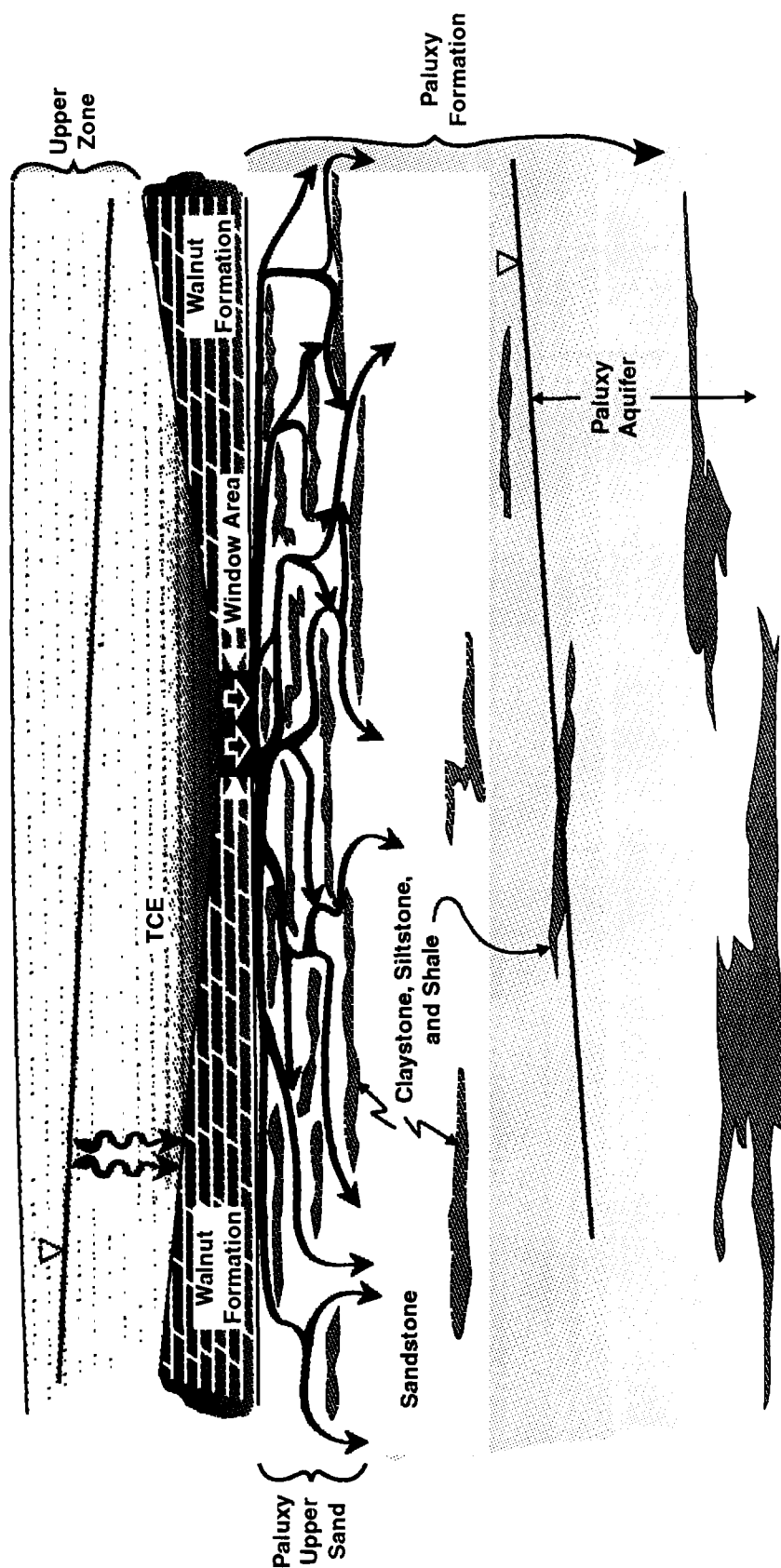


Figure 1-68 Conceptual Model of Contaminant Migration Through the Window Area, Into and Out of the Paluxy Upper Sand, and Into the Paluxy Aquifer.

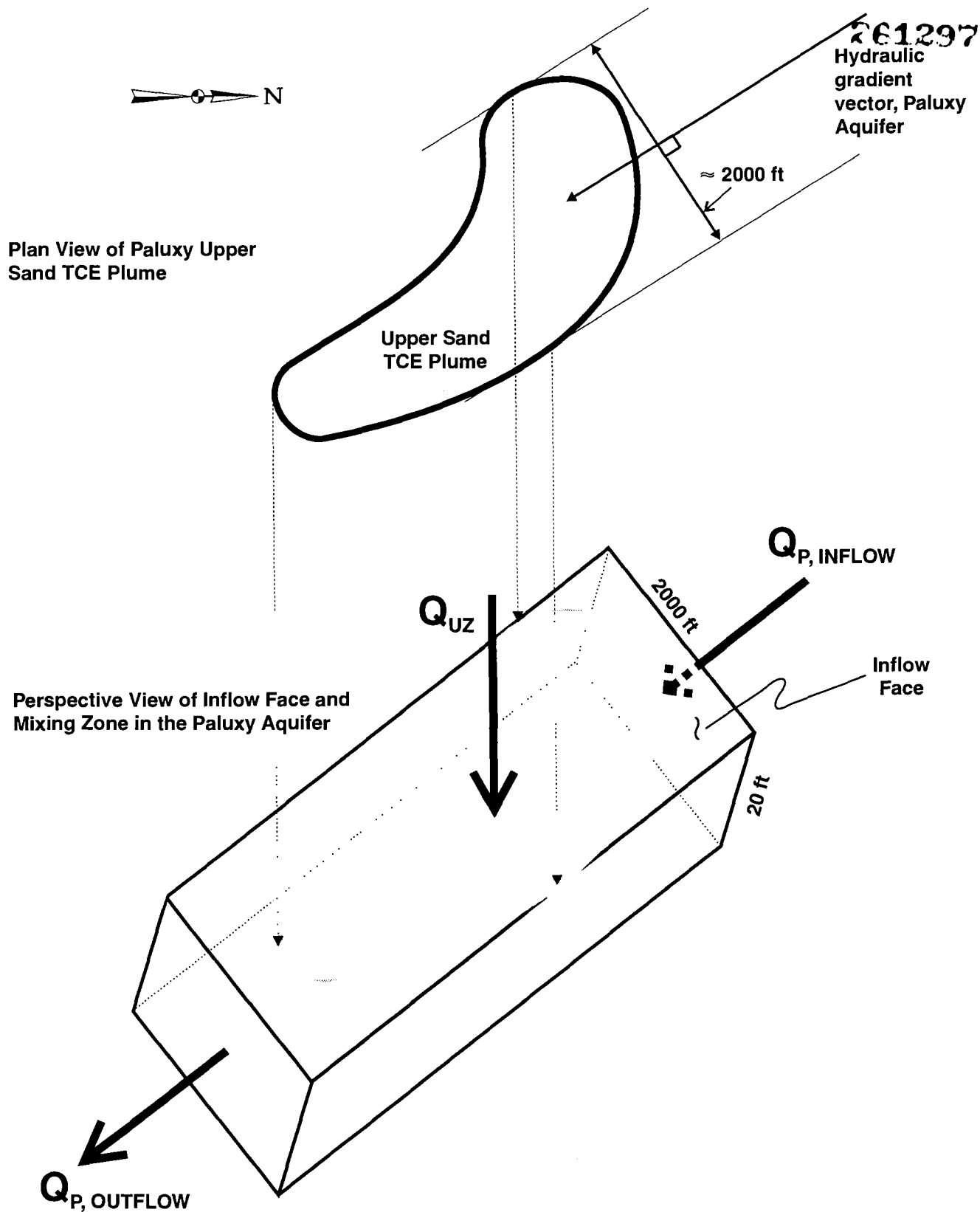


Figure 1-69 Schematic of Conceptual Model for Mixing/Dilution Calculation for Upper Zone, Window Area, Upper Sand, and Paluxy Aquifer.

414 $\mu\text{g/L}$ represents the maximum TCE concentration that can be permitted in upper zone if leakage through the window area is not to cause TCE concentrations in the Paluxy Aquifer to exceed 5 $\mu\text{g/L}$. It is important to note that this estimate is conservative in that it ignored the attenuation processes of sorption, dispersion, and biodegradation. Proof that at least some combination of these attenuation mechanisms are acting to reduce the rate of contaminant migration is provided by noting that window area monitoring wells in the alluvium show TCE concentrations exceeding 20,000 $\mu\text{g/L}$. Monitoring wells completed at the same location as the upper zone wells but screened below the Walnut Formation show at least an order of magnitude decrease in TCE concentration (concentrations typically less than or near 2000 $\mu\text{g/L}$). This characteristic, in a unit that receives all or most of its water from the upper zone in the window area, is most attributable to the attenuation mechanisms discussed above.

In the vicinity of lower Meandering Road Creek, flow into the Paluxy Formation from the creek is not as well understood because the thickness of the Walnut Formation is not known and vertical flow is likely occurring under partially saturated conditions. Because the hydraulic conductivity associated with unsaturated flow is much smaller than for saturated flow, vertical flow velocities in the creek area are likely much smaller than in the window areas. The low hydraulic heads associated with stagnant water pools in the creek also tend to produce relatively small vertical flux rates in this area. Therefore, given the small flux rates and low contaminant concentrations in the creek (compared to those in window area of the upper zone), the vertical mass flux from the creek into the Paluxy Formation is most likely smaller than that estimated for the window area.

The location of the west plume, centered around P-22U and P-M, suggests that vertical migration along a well bore may be the main cause of contamination in the Paluxy on the west side of Plant 4. P-22M was recently abandoned to eliminate the opportunity for contaminant migration down the borehole annulus.

Contaminant Transport in the Paluxy Aquifer Contaminant transport in the Paluxy Aquifer was evaluated using an analytical groundwater transport model. Results of the analytical model, presented in Appendix J of the RI, were used in preparation of the BRA presented in Section 1.7. This approach was taken because the Paluxy Formation water-supply wells in White Settlement have the potential to be impacted by contamination originating at Plant 4. The analytical model used hydraulic head data for the Paluxy Formation generated during the RI and previous investigations. These data included only rough approximations for heads at the White Settlement wells. The analytical modeling indicated that TCE and 1,2-DCE are likely to reach maximum concentrations at all seven of the Paluxy Formation supply wells within 60 years. These estimates are considered very conservative because the model assumes (1) TCE and 1,2-DCE would migrate as conservative tracers with no retardation occurring as a result of adsorption, and (2) one-dimensional flow, which ignores the mixing and dilution that occur in two- or three-dimensional flow.

As previously discussed, TCE and 1,2-DCE adsorption can reduce contaminant migration velocities by more than an order of magnitude. In the Paluxy Formation, this retardation is greatest for the vertical component of flow because the vertical component of flow forces contaminants to move through the interbedded shale and siltstone/claystone deposits. As reported by Huffman Laboratories, Inc. (1991), the organic carbon content of these layers can be as high as 0.22 percent, indicating considerable adsorption capacity. Because contaminants enter the Paluxy Formation at its upper surface and water is withdrawn from the supply wells at the bottom of the formation, the role of vertical flow and retardation is important and will be further analyzed.

For horizontal flow through the cleaner sandstones, the low organic carbon content of 0.06 percent or less (Huffman Laboratories, Inc. 1991) will offer minimal capacity for retardation from adsorption.

1.6.3.2 Contaminant Migration in Surface Water

The surface water pathway at Plant 4 involves three primary features: Meandering Road Creek, Farmers Branch, and Lake Worth. The transport mechanisms associated with the surface water pathway and the significance of those mechanisms at Plant 4 are discussed in the following sections.

Transport Mechanisms

The surface water migration pathway includes transport mechanisms associated with overland flow, stream flow, and lake circulation. Transport via overland flow occurs during rainfall events that are large enough to generate storm-water runoff. Mobile contaminants present at the ground surface are commonly transported in the runoff water. Transport via surface water runoff can be significant in areas where erosion of contaminated surface soil is not inhibited by the presence of surface cover or vegetation. Because the waste sites at Plant 4 are largely covered with pavement or vegetation, overland flow is not considered a significant transport mechanism for contaminants associated with these waste sites. However, contaminants derived from non-point sources at Plant 4 and in the surrounding area can be transported by overland flow. Examples include petroleum hydrocarbons, oil and grease, and other organic compounds commonly derived from parking lots and along roadways.

Transport via stream flow occurs when contaminants that have reached a stream (via groundwater discharge, for example) are advected downstream by the flowing water. This process occurs in Meandering Road Creek, along the west boundary of Plant 4, and also in Farmers Branch, on CAFB. While groundwater discharge to these streams may occur on a nearly continuous basis, the rate of this discharge is so small that contaminant transport within the streams is largely limited to intermittent flows caused by rainfall events. During such events, stagnant water that has collected in the stream channels is diluted by and advected downstream with the storm-water discharge. Contaminants entering Meandering Road Creek are ultimately discharged into Lake Worth. Contaminants entering Farmers Branch are discharged to the West Fork of the Trinity River.

Contaminant transport within Lake Worth involves contaminants that have been discharged to the lake from Meandering Road Creek and other drainages as well as contaminants from non-point sources that reach the lake via overland flow (direct runoff). Once contaminants are in the lake, a number of transport mechanisms act to mix contaminated and uncontaminated water, thereby decreasing influent contaminant concentrations. These mechanisms include the following (Linsley and others 1982):

- Density-current mixing caused by stream inflow
- Near-surface vertical mixing caused by wave action
- Near-shore lateral transport caused by wave action (littoral currents)
- Deep mixing caused by wave-setup and return-flow
- Large-scale mixing caused by semiannual turn-over

Effect on Plant 4 Contaminants

Contaminant transport via the surface water pathway at Plant 4 is primarily controlled by stream flow along Meandering Road Creek and Farmers Branch and lake circulation in Lake Worth. As explained above, overland flow is not considered a significant transport mechanism at Plant 4.

Meandering Road Creek Table 1-107 lists VOCs detected in Meandering Road Creek. The contaminants most commonly reported for samples collected from the creek include TCE, 2-butanone, vinyl chloride, and *cis*-1,2-DCE. These contaminants are commonly found in upper-zone groundwater east of Meandering Road Creek (Landfill No. 3 area) and are likely derived from Plant 4 waste sites. The most frequently detected VOC was *cis*-1,2-DCE. The relatively frequent detections of *cis*-1,2-DCE in the creek can be attributed to both the discharge of *cis*-1,2-DCE in contaminated upper-zone groundwater and the degradation of TCE *after* TCE-contaminated groundwater has been discharged to the creek. Once VOCs have been discharged to the creek and are exposed to sunlight and air, volatilization of the compounds will increase. Biodegradation of TCE, 1,2-DCE, and vinyl chloride to their respective degradation products may increase or decrease upon exposure to sunlight and air depending on the nature of the site-specific biological degradation process. Future contaminant concentrations in Meandering Road Creek are not likely to increase because contaminant levels are not expected to increase at the principle source, Landfill No. 3, located adjacent to the creek. Contaminants present in the creek are transported via stream flow and ultimately discharged to Lake Worth.

Farmers Branch Farmers Branch was sampled at various locations in the spring of 1990 (Radian Corp. 1990) and in October 1991 and February 1992 (Jacobs, December 1991 and April 1992). Samples collected at the inlet to the aqueduct beneath the runway showed no evidence of organic contamination. Samples at the aqueduct outlet and other downstream locations contained TCE ranging from 13 to 1,400 µg/L, and *cis*-1,2-DCE ranging from 5.8 to 380 µg/L. The highest concentrations were measured in downstream samples collected from an area where upper-zone groundwater discharges from Landfill No. 5. Landfill No. 5 is a known source of TCE contamination and is most likely the source of the high TCE and 1,2-DCE concentrations in the nearby portion of Farmers Branch.

Concentrations of TCE and DCE in samples collected between Landfill No. 5 and the aqueduct outlet were typically between 5 and 50 µg/L. These concentrations are indicative of contaminants entering Farmers Branch via discharge of upper-zone groundwater from within the boundary of the East Parking Lot Plume. Because the East Parking Lot Plume originates from a large and highly contaminated source area, TCE concentrations (and those of its degradation products) may still be increasing in the vicinity of the runway and Farmers Branch. Any such increases will likely be accompanied by increases in TCE and DCE concentrations in the segment of Farmers Branch located upstream from Landfill No. 5. As in Meandering Road Creek, volatilization of VOCs will increase after the compounds are discharged into Farmers Branch and exposed to sunlight and air. Biodegradation of VOCs discharged to Farmers Branch may increase or decrease as a result of the exposure to sunlight and air. Contaminants present in Farmers Branch are transported via stream flow and are ultimately discharged to the Trinity River.

Lake Worth As noted in Section 1.5.6.2, carbon disulfide and oil and grease were the only two analytes detected in 9 samples collected from Lake Worth. The carbon disulfide found in the lake was apparently derived from nearby localized sources and does not indicate a widespread

contamination problem in the lake. The same applies to oil and grease, which were found in only one background sample and which may be derived from non-point source runoff from urban unpaved areas and which may be derived from power boats operated on the lake.

These results suggest that the lake transport mechanisms, the large volume of water stored in the lake, and the continuous through-flow provided by the West Fork of the Trinity River combine to dilute virtually all contaminants entering the lake from Meandering Road Creek and other non-point source areas.

1.6.3.3 Contaminant Migration in Air

As discussed in the BRA (see Section 1.7), contaminant migration via the air pathway at Plant 4 does not increase human-health risks for the general public. The primary transport mechanisms associated with the air pathway and the effect of those pathways on contaminants at Plant 4 are discussed below.

Transport Mechanisms

The air migration pathway includes three transport mechanisms: advection, mechanical dispersion, and molecular diffusion. Advection and mechanical dispersion require movement of air mass and are functions of wind speed and turbulence, respectively. Contaminant migration via molecular diffusion is of concern only in settings characterized by very low air-flow velocities. Because calm conditions occur infrequently at Plant 4 (see Table 1-113), advection and mechanical dispersion are considered the dominant transport mechanisms.

Effect on Plant 4 Contaminants

The results of the air monitoring presented in Section 1.5.8 show that Plant 4 does have an impact on the concentration of airborne contaminants. However, several factors indicate that this impact is associated with ongoing industrial activities at the facility and is not related to the 21 RI/FS waste sites.

Except for the compounds dichlorodifluoromethane (Freon 12) and 1,1,1-TCA, contaminant concentrations exceeding background levels were observed only when winds were from the south (see Section 1.5.8). Likely sources for elevated contaminant concentrations in southerly winds are chemicals used in manufacturing and testing processes in the vicinity of the Parts Plant/Assembly Building.

Freon 12 and 1,1,1-TCA were found at elevated concentrations in both northerly and southerly winds (see Section 1.5.8). Freon 12 is likely derived from tanks of Freon compounds that are stored and used throughout the area surrounding the on-site air monitoring station. The compound 1,1,1-TCA may be attributed to laboratory contamination because this compound was found in the laboratory blanks associated with all but four of the samples containing elevated concentrations of 1,1,1-TCA.

Lastly, it should be noted that all of the 21 RI/FS waste sites are covered with asphalt, concrete, or established vegetation such as grass. These surface coverings reduce the potential for significant volatilization or wind erosion at the waste sites.

1.7 Baseline Risk Assessment (BRA)

The BRA was conducted using the methods described in the *EPA Risk Assessment Guidance for Superfund - Human Health Evaluation Manual* (EPA 1989a) and the *EPA Framework for Ecological Risk Assessment* (EPA 1992). The general methodology consists of identifying contaminants of concern for human health and ecological risk; determining the exposure route of the contaminants to potential receptors; assessing the toxicity of the contaminants of concern; and combining the contaminants, contaminant toxicity, and exposure routes to quantify the human and ecological risks.

1.7.1 Human Health Risk Assessment

For each identified human pathway, a reasonable maximum exposure (RME) scenario has been developed. This scenario gives a reasonable upper-bound estimate of the potential magnitude of an individual exposure to chemicals from the site. Moreover, when applicable, an exposure estimate using central tendency data was developed. Central tendency provides a more typical or average value than RME.

Human health risks are quantified in terms of incremental lifetime cancer risk (ILCR) for carcinogenic contaminants. The ILCR is expressed in terms of additional cancers. For example a 1×10^{-6} ILCR indicates a one in one million increase in the probability that an individual will develop some form of cancer from exposure to the contaminants of concern for a given site.

Non-carcinogenic health risks are quantified in terms of the hazard index (HI). The HI represents a comparison of projected exposure levels to what is considered to be the acceptable limit of exposure. The HI is based on the ratio of the estimated daily intake to an acceptable daily exposure.

Human health risks are quantified for both current and future land use scenarios, Tables 1-120, 1-121, 1-122, and 1-123 summarize the ILCR for the Plant 4 site. Tables 1-124, 1-125, and 1-126 summarize the HI for the Plant 4 site.

Table 1-120. Summary of Potential Incremental Lifetime Cancer Risk: Current Land Use

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>ILCR</u>
Benzene	Occupational ingestion of soil	9.0×10^{-10}
Benzo(a)anthracene	Occupational ingestion of soil	1.7×10^{-7}
Benzo(a)pyrene	Occupational ingestion of soil	1.6×10^{-8}
Benzo(b)fluoranthene	Occupational ingestion of soil	1.9×10^{-7}
Benzo(k)fluoranthene	Occupational ingestion of soil	1.6×10^{-7}
Benzene	Occupational inhalation of contaminated air	1.8×10^{-8}
Chromium	Occupational inhalation of contaminated air	1.2×10^{-5}
Methylene Chloride	Occupational inhalation of contaminated air	2.7×10^{-8}
Trichloroethene	Occupational inhalation of contaminated air	1.5×10^{-6}
Vinyl Chloride	Dermal exposure during swimming	2.1×10^{-7}

**Table 1-121. Summary of Potential Incremental Lifetime Cancer Risk (Central Tendency):
Current Land Use**

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>ILCR</u>
Benzene	Occupational ingestion of soil	3.2×10^{-10}
Benzo(a)anthracene	Occupational ingestion of soil	6.0×10^{-8}
Benzo(a)pyrene	Occupational ingestion of soil	5.8×10^{-7}
Benzo(b)fluoranthene	Occupational ingestion of soil	6.9×10^{-8}
Benzo(k)fluoranthene	Occupational ingestion of soil	5.6×10^{-8}
Benzene	Occupational inhalation of contaminated air	6.5×10^{-7}
Chromium	Occupational inhalation of contaminated air	4.4×10^{-6}
Methylene Chloride	Occupational inhalation of contaminated air	9.8×10^{-9}
Trichloroethene	Occupational inhalation of contaminated air	5.4×10^{-7}
Vinyl Chloride	Dermal exposure during swimming	6.3×10^{-8}

Table 1-122. Summary of Potential Incremental Lifetime Cancer Risk: Future Land Use

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>ILCR</u>
Trichloroethene	Ingestion of groundwater	1.3×10^{-4}
Trichloroethene	Inhalation of VOCs during showering	1.6×10^{-4}
Trichloroethene	Dermal exposure during showering	5.0×10^{-5}

**Table 1-123. Summary of Potential Incremental Lifetime Cancer Risk (Central Tendency):
Future Land Use**

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>ILCR</u>
Trichloroethene	Ingestion of groundwater	2.8×10^{-5}
Trichloroethene	Inhalation of VOCs during showering	4.7×10^{-5}
Trichloroethene	Dermal exposure during showering	1.5×10^{-5}

Table 1-124. Summary of Potential Hazard Index: Current Land Use

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>HI</u>
Naphthalene	Occupational ingestion of soil	1.7×10^{-4}
Pyrene	Occupational ingestion of soil	3.1×10^{-5}
Fluoranthene	Occupational ingestion of soil	3.3×10^{-5}
Cadmium	Occupational ingestion of soil	1.9×10^{-3}
Chromium	Occupational ingestion of soil	2.0×10^{-6}
Copper	Occupational ingestion of soil	3.0×10^{-2}
Nickel	Occupational ingestion of soil	4.7×10^{-3}
Zinc	Occupational ingestion of soil	1.5×10^{-2}
Benzene	Occupational inhalation of contaminated air	1.7×10^{-3}
Chromium	Occupational inhalation of contaminated air	4.2×10^{-1}
Methylene Chloride	Occupational inhalation of contaminated air	5.3×10^{-5}
Zinc	Occupational inhalation of contaminated air	2.5×10^{-5}
Cis-1,2-dichloroethene	Dermal Exposure while swimming	8.2×10^{-4}

Table 1-125. Summary of Potential Hazard Index: Future Land Use

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>HI</u>
Barium	Ingestion of groundwater	3.9×10^{-2}
Chromium	Ingestion of groundwater	3.6×10^{-2}
1,1-Dichloroethane	Ingestion of groundwater	3.8×10^{-3}
1,2-Dichloroethene	Ingestion of groundwater	1.0
Toluene	Ingestion of groundwater	9.5×10^{-4}
1,1-Dichloroethane	Inhalation of VOCs during showering	3.1×10^{-3}
Toluene	Inhalation of VOCs during showering	2.5×10^{-4}
Barium	Dermal exposure during showering	6.4×10^{-5}
Chromium	Dermal exposure during showering	1.4×10^{-4}
1,1-Dichloroethane	Dermal exposure during showering	6.3×10^{-6}
1,2-Dichloroethene	Dermal exposure during showering	1.7×10^{-3}
Toluene	Dermal exposure during showering	1.9×10^{-3}

Table 1-126. Summary of Potential Hazard Index (Central Tendency): Future Land Use

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>HI</u>
Barium	Ingestion of groundwater	2.7×10^{-2}
Chromium	Ingestion of groundwater	2.5×10^{-2}
1,1-Dichloroethane	Ingestion of groundwater	2.7×10^{-3}
1,2-Dichloroethene	Ingestion of groundwater	7.0×10^{-1}
Toluene	Ingestion of groundwater	6.6×10^{-4}

The results of the BRA at Plant 4 indicate the constituents listed in Table 1-127 may require remedial action, from a human health standpoint.

In general, the threshold values of ILCR and HI above which remedial action may be necessary are 1.0×10^{-6} and 1.0, respectively (EPA 1991a). Table 1-127 lists the constituents and pathways which may pose an unacceptable risk. Constituents presenting smaller health risks generally should not be retained as contaminants of concern (EPA 1991a).

Table 1-127. Summary of Constituents that may Require Remedial Action

<u>Constituent</u>	<u>Exposure Pathway</u>	<u>ILCR</u>	<u>HI</u>	<u>ILCR</u> (Central Tendency)	<u>HI</u> (Central Tendency)
Benzo(a)pyrene	Occupational ingestion of soil	1.6×10^{-6}		5.8×10^{-7}	
Benzene	Occupational inhalation of contaminated air	1.8×10^{-6}		6.5×10^{-7}	
Chromium	Occupational inhalation of contaminated air	1.2×10^{-5}		4.4×10^{-6}	
Trichloroethene	Occupational inhalation of contaminated air	1.5×10^{-6}		5.4×10^{-7}	
Trichloroethene	Ingestion of groundwater	1.3×10^{-4}		2.8×10^{-5}	
Trichloroethene	Inhalation during showering	1.6×10^{-4}		4.7×10^{-5}	
Trichloroethene	Dermal exposure during showering	5.0×10^{-5}		1.5×10^{-5}	
1,2-Dichloroethene	Ingestion of groundwater		1.0		0.7

In summary, from the human health risk perspective, benzo(a)pyrene in soil may require remedial action and TCE and 1,2-DCE in the groundwater may require remedial action.

Chromium, TCE, and benzene were shown to present an unacceptable health risk as an air contaminant based on the data gathered by the air monitoring stations. However, the measured

chromium levels in the air did not correlate with the presence of Plant 4. Chromium levels measured at the off-site sampling location were similar in magnitude and variability to the chromium levels measured on site. Additionally, the observed chromium concentrations appear to be independent of the wind speed and direction (see Section 1.5.8). This suggests that the levels of chromium in the air would not be mitigated by remedial actions at the site and, therefore, chromium should not be considered for remedial action as an air contaminant.

The TCE concentrations measured in air correlate directly with wind direction. When the wind direction is from the Assembly Building/Parts Plant toward the air sampling station, the TCE levels increase. When the wind direction reverses, the TCE levels drop significantly, and in many cases could not be detected (see Section 1.5.8). This suggests that the presence of TCE in the air is the result of on-going Plant 4 operations and, therefore, should not be considered for remedial action as an air contaminant.

The benzene concentrations measured in the air on site were comparable to the off site concentrations. Also, benzene levels appear to be independent of wind direction at both the off-site and on-site sampling locations, indicating the ubiquitous nature of the contaminant. Consequently, remedial actions at Plant 4 would not be expected to mitigate the benzene air contaminant levels, therefore, no remedy for benzene as an air contaminant shall be proposed.

The results of the Central Tendency Evaluation reduce the calculated health risk values in some cases below the recognized thresholds for possible remedial actions. The Central Tendency results are considered in the proposal of remedial action alternatives.

1.7.2 Ecological Risk Assessment

The Plant 4 ecological risk assessment focused on the relatively natural areas near Meandering Road Creek and Lake Worth. In addition, the risk assessment addressed the aquatic community in Farmers Branch Creek.

Contaminants detected in Landfill 3 and 4 soils, Meandering Road Creek and Lake Worth surface water, and Meandering Road Creek and Lake Worth sediments were screened to form medium-specific lists of contaminants of potential concern (CoPCs).

Receptors of potential concern (RoPCs) were selected using the following criteria: (1) high likelihood of exposure to CoPCs, (2) high ecological significance, (3) availability of toxicological literature for the species or surrogate, and (4) possibility of population-level adverse effects from Plant 4 stressors. RoPCs for Plant 4 include the largemouth bass (*Micropterus salmoides*), the red-tailed hawk (*Buteo jamaicensis*), the red fox (*Vulpes fulva*), the raccoon (*Procyon lotor*), terrestrial prey species (i.e. small mammals), and aquatic prey species (i.e. benthic macroinvertebrates and small fish).

Assessment endpoints (actual environmental values that are to be protected) were selected to represent the receptors of concern. Plant 4 assessment endpoints include the protection of largemouth bass, red-tailed hawk, red fox, and raccoon populations, and protection of overall aquatic and terrestrial prey populations.

Measurement endpoints (characteristics of the ecological system that can be related to assessment endpoints) for Plant 4 included (1) measuring contaminant concentrations in surface water, sediment, soil, and fish tissue; (2) modeling food web uptake of contaminants; (3) assessing direct toxicity of environmental media; and (4) conducting surface water toxicity tests.

Ecological risk was characterized using a weight-of-evidence approach in which all of the data generated by the measurement endpoints were considered. In the food web models and direct toxicity assessments, ecological risk was quantified by calculating hazard quotients such that hazard quotient equals the measured dose or concentration divided by an ecotoxicological benchmark value. A hazard quotient that exceeds 1.0 indicates potential ecological risk.

The results of the toxicity tests were inconclusive, so they were not used to quantify risk.

Hazard quotients exceeded 1.0 for terrestrial prey species (white-footed mice) exposed to soil at two locations in Landfill 3 and at three locations in Landfill 4, for largemouth bass exposed to sediments at one location in Meandering Road Creek Inlet, and for aquatic prey species exposed to sediments at one location in Meandering Road Creek and at two locations in Meandering Road Creek Inlet. Hazard quotients did not exceed 1.0 for the red-tailed hawk, red fox, or raccoon.

To address ecological risk in Farmers Branch Creek, maximum concentrations of the CoPCs detected in Farmers Branch Creek were compared concentrations at which the hazard quotient equalled 1.0 in the Meandering Road Creek model. Based on this comparison, no hazard quotients would exceed 1.0 for fish in Farmers Branch Creek. Therefore, it is unlikely that fish in Farmers Branch Creek are at risk from Plant 4 contaminants.

2.0 Identification and Screening of Technologies

The purpose of the feasibility study (FS) is to develop and evaluate remedial alternatives for contaminated sites on Air Force Plant 4 that cause excessive risk to human health and the environment. The remedial alternatives are evaluated as to whether they eliminate, reduce, or control risks to human health and the environment, as identified by the baseline risk assessment (BRA), and are in compliance with applicable or relevant and appropriate requirements (ARARs). The process by which this occurs is directed by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and follows the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988a). The process includes identifying and screening technologies that may be applicable to the contamination problems. The most appropriate technologies are then assembled into remedial action alternatives. Once these alternatives have been compiled, a detailed analysis of each alternative is done to better determine a potential site-wide remedial solution.

2.1 Air Force Plant 4 Sites/Areas of Concern

Sites on Air Force Plant 4 and areas of concern that were investigated as part of the RI are listed in Table 2-1. The table is arranged by media: soil/sediment, groundwater, and surface water. Groundwater contamination does not lend itself to site boundaries like soil and sediment. Therefore, rather than addressing the groundwater on a site by site basis, the groundwater was addressed by aquifer and areas of contamination within each aquifer. Table 2-1 briefly lists the site or areas of concern, BRA findings, voluntary actions completed or ongoing at a site, and whether remedial alternatives are being developed in this FS Report for the site or media.

Table 2-1. Summary of the Air Force Plant 4 Sites

Site	Findings	Voluntary Actions/ Proposed Action
Media: Soil/Sediment		
Landfill No. 1 (Site LF01)	BAP exceeded the human health risk threshold value. However, the BAP is suspected to be from asphalt paving fragments and not from past waste disposal practices.	Completed voluntary action to remove contaminated soil. No further response action planned.
Landfill No. 2 (Site LF02)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Landfill No. 3 (Site LF03)	Copper, lead, and zinc exceed ecological risk thresholds. Contaminants do not pose an unacceptable risk to human health or the environment.	Remedial action alternatives developed in FS.

Table 2-1 (continued) Summary of the Air Force Plant 4 Sites

Site	Findings	Voluntary Actions/ Proposed Action
Landfill No. 4 (Site LF04)	BAP exceeds human health risk threshold and arsenic, cadmium, and copper exceed ecological risk thresholds.	Remedial action alternatives developed in FS.
Fire Department Training Area (FDTA) No. 2 (Site FT05)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-3 (Site FT06)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-4 (Site FT07)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-5 (Site FT08)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
FDTA-6 (Site FT09)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Chrome Pit No. 1 (Site DP10)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Chrome Pit No. 2 (Site DP11)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Chrome Pit No. 3 (Site DP12)	Suspected TCE DNAPL area, although contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Die Yard Chemical Pits (Site DP13)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove contaminated soil. No further response action planned.
Fuel Saturation Area (FSA) No. 1 (Site SS14)	Fuel contamination at site, although contaminants do not pose an unacceptable risk to human health or the environment.	Installed groundwater recovery system and vadose zone bioventing system. No further response action planned.
FSA-2 (Site SS15)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.

Table 2-1 (continued) Summary of the Air Force Plant 4 Sites

Site	Findings	Voluntary Actions/ Proposed Action
FSA-3 (Site SS16)	Fuel contamination at the site, although contaminants do not pose an unacceptable risk to human health or the environment.	Installed groundwater recovery system and vadose zone bioventing system. No further response action planned.
Former Fuel Storage Area (Site SS17)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Solvent Lines (Site SS18)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Nuclear Aerospace Research Facility (Site OT19)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Waste Water Collection Basins (Site WP20)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
West Compass Rose (Site OT21)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
East Parking Lot/Flight Line (Site OT22)	Soil is not considered part of this site, only groundwater.	Not applicable, soil not included as part of this site.
French Drain (Site OT23)	French Drain is part of LF No. 1.	French Drain is a voluntary action at LF No. 1
Jet Engine Test Stand (Site OT24)	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Underground Storage Tank (UST) No. 19 (Site ST25)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned.
UST No. 20 (Site ST26)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned.
UST No. 24A (Site ST27)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned

Table 2-1 (continued) Summary of the Air Force Plant 4 Sites

Site	Findings	Voluntary Actions/ Proposed Action
UST No. 24B (Site ST28)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
UST No. 25A (Site ST29)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
UST No. 30 (Site ST30)	Contaminants do not pose an unacceptable risk to human health or the environment.	Completed voluntary action to remove UST. No further response action planned
Assembly Building/Parts Plant Perimeter (Building 181)	Contaminants do not pose an unacceptable risk to human health or the environment, although, TCE is in the vadose zone which causes groundwater contamination.	Ongoing voluntary action (soil vapor extraction and vapor enhanced pumping) to remove TCE in the vadose zone. Remedial action alternatives developed in FS.
Meandering Road Creek (includes inlet to Lake Worth)	Silver exceeds ecological risk thresholds. Contaminants do not pose an unacceptable risk to human health.	Remedial action alternatives developed in the FS.
Media: Groundwater		
Paluxy aquifer	TCE and 1,2-DCE cause unacceptable human health risk in two areas: (1) East plume under the East Parking Lot. (2) West plume under LF No. 3	Remedial action alternatives developed in FS.
Upper Zone flow system - East Parking Lot Plume	TCE and DCE contamination is the source of contamination in the Paluxy aquifer. Suspected DNAPL at the Assembly Building and Window Area. Targeted for potential remedial action because of hydraulic connection to the Paluxy aquifer.	Ongoing voluntary actions at the East Parking Lot to extract and treat contaminated groundwater in the Window Area. Remedial action alternatives developed in the FS.
Upper Zone flow system - West Plume	Contaminants do not pose an unacceptable risk to human health or the environment.	Ongoing voluntary actions for groundwater include collection of leachate at LF No.1, French Drains No. 1 and No. 2. Leachate is treated at FSA-1
Upper Zone flow system - North Plume	Contaminants do not pose an unacceptable risk to human health or the environment.	Ongoing voluntary action at FSA-3 to remove LNAPL and extract and treat groundwater.

Table 2-1 (continued) Summary of the Air Force Plant 4 Sites

Site	Findings	Voluntary Actions/ Proposed Action
Media: Surface Water		
Meandering Road Creek	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.
Lake Worth	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned
Farmers Branch Creek	Contaminants do not pose an unacceptable risk to human health or the environment.	No response action planned.

2.2 Ongoing Voluntary Actions

Air Force Plant 4 currently has seven voluntary actions that are ongoing. One of the actions is being done on CAFB. Ongoing voluntary actions are briefly mentioned in Table 2-1 and are described in more detail in this section. A more detailed description of past and ongoing voluntary actions is presented in the report *Summary of Remediation Projects at Air Force Plant 4 and Carswell Air Force Base* (Environmental Science & Engineering 1994a). The report also provides a listing of previous reports relevant to Air Force Plant 4 and Carswell Air Force Base.

2.2.1 Landfill No. 1, French Drains No. 1 and No. 2

French Drain No. 1 was installed in November 1982 as a response to complaints of odors coming from Stormwater outfall No. 5. The French Drain system consists of 90 feet of perforated four-inch drain pipe. The pipe is placed on bedrock east of Stormwater No. 5 outfall. During excavation, two six-inch perforated pipes were found. The pipes were apparently installed before the parking lot was paved in 1967. The six-inch pipes also were connected to the system. French Drain No. 2 was installed in 1983 in the area of the former waste oil pits which was a suspected source of residual contamination. The area was excavated to bedrock and six 24-inch drainlines were placed in the bottom of the excavation and connected to a collector box.

Prior to operation of French Drain No. 2, French Drain No. 1 was evacuated daily. Initially, the evacuated water was deep well injected and later the disposal method was incineration. After operation of French Drain No. 2 began, groundwater collected from French Drain No. 1 was diverted to the sanitary sewer. However, after May 1990 evacuation to the sanitary sewer was no longer considered feasible and the drains remained inactive until October 1992 when the evacuated groundwater was treated at FSA-1. Groundwater from the drains is currently treated at FSA-1.

Although contamination exists at Landfill No. 1, the BRA found that contaminant levels in the soil and groundwater at Landfill No. 1 do not pose an unacceptable risk to human health or the environment. Therefore, remedial alternatives will not be developed.

2.2.2 Landfill No. 3

A vacuum-enhanced extraction system has been installed at Landfill No. 3. The system consists of 42 extraction wells spaced 20 feet apart and a trench 150 feet long with four extraction points. The wells and trench are located along the western edge of Landfill No. 3. The wells are four inches in diameter. The trench was installed where depth to bedrock was shallow, approximately four feet.

The vacuum-enhanced extraction system was chosen for this site because of the low permeability of the aquifer in this area. The extraction wells are designed to extract contaminated groundwater using a drop tube inside the well casing and also extract VOCs in the vadose zone with a vacuum applied to the well. Treatment of the extracted groundwater would be with an air stripper and the extracted vapor would be treated with carbon adsorption units.

Although contamination still exists at Landfill No. 3, the BRA found that contaminant levels in the soil and groundwater do not exceed human health risk threshold values. However, contamination in the soil did exceed ecological risk threshold values. The voluntary actions serve to remove some of the suspected TCE DNAPL which would reduce the time until contamination reaches levels that no longer require monitoring.

2.2.3 Building 181

A pilot-scale soil vapor extraction (SVE) system has been installed and operated at Building 181 to extract TCE from the vadose zone. The TCE in the vadose zone under Building 181 is the result of spills and leaks from TCE tanks in the building. The TCE in the vadose zone has migrated down to the Upper Zone groundwater under Building 181.

The objectives of the pilot-scale system were to remove as much contaminant from the subsurface as possible within the time period of the test, 90 days, and to develop pilot test parameters necessary to evaluate the applicability of a full-scale SVE system. The pilot-scale SVE system used eight extraction wells to withdraw the TCE from the soil. The extracted vapor was treated with carbon adsorption after condensate removal.

The pilot-scale system was successful in extracting TCE. Approximately 4,400 pounds (367 gallons) of TCE were extracted, as measured by carbon vessel removal. Problems encountered with the system were considered minor. Groundwater was found in one of the extraction wells. Low ambient air temperatures caused condensate in the carbon vessels. This reduced the carbon removal efficiencies resulting in shorter carbon changeout cycles. The problem was corrected by insulation and heat tracing.

The SVE pilot-scale system was found to be effective at removing TCE from the vadose zone. The study recommended increased areal coverage, increased blower capacity and vacuum to accommodate increased system size, installation of groundwater vacuum-enhanced treatment system (consisting of air stripping and carbon adsorption), and removal of perched groundwater (groundwater above the Upper Zone flow system).

The TCE in the vadose zone is a source of contamination that dissolves in the Upper Zone groundwater and ultimately works its way to Paluxy aquifer through the Window Area in the East Parking Lot. The TCE in the vadose zone is a source of risk and remedial alternatives will be developed in the FS.

2.2.4 East Parking Lot

Air Force Plant 4 initiated a groundwater extraction and treatment system in the Window Area of the East Parking Lot in January 1993. Three phases of the project will be completed. At the end of Phase III, a total of eleven extraction wells are planned. The system includes extraction wells, a treatment system, and piping to convey the extracted groundwater to the treatment system. The treatment system consists of an equalization tank, an air stripper, and a carbon adsorption unit used as a polishing step. Treated water is discharged to the POTW.

After Phase II (seven extraction wells installed) the TCE concentrations at the influent to the treatment system ranged from 9,000 $\mu\text{g/L}$ to 21,000 $\mu\text{g/L}$. By October 1994, approximately 4,200,000 gallons had been pumped and treated and a total of 40 gallons of TCE had been removed from the groundwater. Pumping demonstrated that the aquifer is very heterogeneous. Wells in close proximity to each other would have dramatically different yields.

Contamination in the East Parking Lot Plume is the source of contamination in the Paluxy aquifer because the two aquifers are hydraulically connected. The BRA determined that TCE contamination in the Paluxy aquifer exceeds human health risk threshold values. Remedial alternatives for the East Parking Lot Plume will be developed in the FS.

2.2.5 Fuel Saturation Area No. 1

The ongoing voluntary action at FSA-1 is a groundwater treatment system. The site was reportedly contaminated by fuels leaking from an underground distribution system and leaking USTs. The system at FSA-1 is designed to extract groundwater and fuel on the groundwater and then treat the extracted fuel or groundwater. It has a design capacity of 70 gallons per minute and consists of an oil/water separator, an air stripper, and carbon adsorption units. Groundwater is recovered from two extraction wells. Groundwater evacuated from French Drains No. 1 and No. 2 also are treated at FSA-1.

The Air Force has initiated a pilot-scale bioventing system at FSA-1 to test the feasibility of such a system. The bioventing system is designed to enhance natural biodegradation of fuel related hydrocarbons by supplying oxygen to the subsurface. The system is fairly simple, it includes vent wells where the oxygen is injected into the subsurface, monitoring points, and a blower to force the oxygen into the vent wells.

Although contamination exists at FSA-1, the BRA found that contaminant levels in the soil and groundwater do not exceed human health or ecological risk threshold values. Remedial alternatives will not be developed. The voluntary action serves to remove LNAPL which will reduce the time until contamination reaches levels that no longer require monitoring.

2.2.6 Fuel Saturation Area No. 3

The voluntary action at FSA-3 is a groundwater treatment system. The site was reportedly contaminated by fuels leaking from an underground distribution system and leaking USTs. The system at FSA-3 is designed to extract groundwater and fuel on the groundwater and then treat the extracted fuel or groundwater. It has a design capacity of 20 gallons per minute and consists of an oil/water separator and a low-profile air stripper. Groundwater is recovered from eight extraction wells.

The Air Force has initiated a pilot-scale bioventing system at FSA-3 to test the feasibility of such a system. The bioventing system is designed to enhance natural biodegradation of fuel related hydrocarbons by supplying oxygen to the subsurface. The system is fairly simple, it includes vent wells where the oxygen is injected into the subsurface, monitoring points, and a blower to force the oxygen into the vent wells.

Although contamination exists at FSA-3, the BRA found that contaminant levels in the soil and the groundwater do not exceed human health or ecological risk threshold values. Remedial alternatives will not be developed. The voluntary action serves to remove LNAPL, which will reduce the time until contamination reaches levels that no longer require monitoring.

2.2.7 Carswell Air Force Base Landfills No. 4 and No. 5

Groundwater extraction and treatment downgradient of CAFB Landfills No. 4 and No. 5 has been initiated as a voluntary action by Air Force Plant 4. Even though the site is on CAFB, Air Force Plant 4 undertook the action because contamination from the East Parking Lot Plume has migrated onto CAFB.

Phases I and II of the voluntary action installed seven groundwater extraction wells and a treatment system that uses air stripping and carbon adsorption. The extracted groundwater is contaminated with dissolved TCE. Phase III of the project plans to install an additional four extraction wells. The treatment system has been effective in treating the extracted groundwater but has had minor problems. One problem encountered was carbonate buildup in piping. Scale inhibitor (acid neutralization) was introduced to the influent which has reduced the amount of buildup.

Dissolved TCE concentrations in the extraction wells range from 300 $\mu\text{g/L}$ to 4,000 $\mu\text{g/L}$, averaging around 1,500 $\mu\text{g/L}$ at the influent to the treatment system. The volume of groundwater pumped has increased as the number of extraction wells increased. By October 1994, seven extraction wells were in-place and approximately 17,700,000 gallons had been pumped and treated with a total of 19 gallons of TCE removed from the groundwater.

Upgradient of CAFB Landfills No. 4 and No. 5, the TCE plume is caused entirely by contamination on Air Force Plant 4. Downgradient of the landfills, TCE concentrations are higher than they are upgradient of the landfills. This indicates that contamination in the landfills is responsible for a portion of the downgradient TCE plume.

The dissolved TCE in the groundwater recharges surface water causing TCE contamination in the surface water on CAFB. However, the BRA found that present levels of TCE in surface waters on CAFB do not exceed risk threshold values. Also, any remediation of the East Parking Lot Plume would reduce TCE concentrations in the groundwater thereby reducing TCE concentrations in CAFB surface waters. This would result in risk levels below current risk levels. Because concentrations currently do not exceed risk thresholds and remedial actions on Air Force Plant 4 would reduce risk below current levels, remedial alternatives for Landfills No. 4 and No. 5 will not be developed.

2.3 Remedial Action Objectives

In general, remedial action objectives (RAOs) identify specific chemicals of concern (COCs) that exceed the threshold levels for human health or ecological risk, exposure pathways for those COCs, and preliminary remediation goals (PRGs). PRGs are numerical concentration target values for specific COCs in specific media. The BRA determines the specific COCs that exceed human health and ecological risk threshold values and the exposure pathways for those COCs.

Human health risks are quantified in terms of incremental lifetime cancer risk (ILCR) for carcinogenic contaminants. The ILCR is expressed in terms of additional cancers. For example a 1×10^{-6} ILCR indicates a one in one million increase in the probability that an individual will develop some form of cancer from exposure to the COC for a given site. Non-carcinogenic health risks are quantified in terms of the hazard index (HI). The HI represents a comparison of projected exposure levels to what is considered to be the acceptable limit of exposure. The HI is based on the ratio of the estimated daily intake to an acceptable daily exposure.

In general, the human health threshold values of ILCR and HI above which remedial action may be necessary are 1.0×10^{-6} and 1.0, respectively (EPA 1991a). However, an ILCR range of 1×10^{-4} to 1×10^{-6} may be an acceptable health risk depending upon site specific considerations. An ILCR greater than 1×10^{-4} generally requires remedial action. Constituents presenting smaller health risks generally should not be retained as COCs (EPA 1991a).

Ecological risk is assessed using a weight-of-evidence approach in which quantitative and qualitative data for multiple receptors are considered. Quantitative data usually are expressed as hazard quotients (HQs), where the HQ is the ratio of a measured or calculated dose of a contaminant to a known toxic dose of the contaminant. A HQ that exceeds 1.0 indicates a potential for ecological risk. Qualitative data that can be used in ecological risk assessments are variable, ranging from visible effects of contamination (i.e. lack of vegetation) to non-quantitative toxicity test results. When different types of data for different receptors contradict each other, risk assessors use professional judgement to determine how much emphasis is placed on each data type or receptor.

The COCs that exceed human health or ecological risk thresholds are listed in Table 2-2 along with their associated exposure pathways.

Table 2-2 Contaminants of Concern Exceeding Threshold Values

Media	COC	Exposure Pathway(s)
COCs based on Human Health Risk		
Paluxy groundwater	TCE	ingestion of groundwater inhalation during showering dermal exposure during showering
	1,2-DCE	ingestion of groundwater
Soil	Benzo(a)pyrene (BAP)	occupational ingestion of soil
Air	TCE	occupational inhalation of contaminated air
	Chromium	occupational inhalation of contaminated air
	Benzene	occupational inhalation of contaminated air
COCs based on Ecological Risk		
Soil/Sediment	Silver	toxicity to aquatic organisms
	Copper	exposure to mice
	Lead	exposure to mice
	Zinc	exposure to mice
	Arsenic	exposure to mice
	Cadmium	exposure to mice

2.3.1 Groundwater

Typically, the remedial action objective for contaminated groundwater is to prevent direct human exposure to groundwater that contains harmful levels of contamination. There are two ways of accomplishing this: remediate the groundwater so that it no longer contains harmful levels of contamination or prevent access to the contaminated groundwater (i.e., plume containment or institutional controls).

Air Force Plant 4 is underlain by the Paluxy aquifer and the Upper Zone flow system. Three different plumes exist within the Upper Zone flow system and two plumes exist in the Paluxy aquifer. Development of RAOs has been organized by aquifer or flow system and by contaminant plumes within the Upper Zone flow system.

2.3.1.1 Paluxy Aquifer

PRGs were developed for each Paluxy aquifer COC shown in Table 2-2. PRGs are generally based on chemical-specific ARARs (if they exist) or calculated based on human health or ecological risk considerations. The COCs for the Paluxy aquifer are TCE and 1,2-DCE.

The contaminant 1,2 DCE is a noncarcinogen. An HI value of 1.0 for 1,2-DCE corresponds to a concentration of 370 $\mu\text{g/L}$ and, therefore, a PRG based on the HI would be 370 $\mu\text{g/L}$. However, another factor to consider in developing PRGs is chemical-specific ARARs. Chemical-specific ARARs for groundwater depend on whether the groundwater is a source of drinking water. If the groundwater is a source of drinking water, the maximum contaminant levels (MCLs) specified in the Safe Drinking Water Act (SDWA) are generally an applicable or relevant and appropriate standard (EPA 1987). The groundwater in the Paluxy aquifer at Plant 4 meets the definition of a drinking water aquifer.

The MCLs for the two isomers of 1,2-DCE are 70 $\mu\text{g/L}$ for *cis*-1,2-DCE and 100 $\mu\text{g/L}$ for *trans*-1,2-DCE. Since MCL concentrations are lower than the concentration that corresponds to an HI value of 1.0, the MCL concentrations will be used as the PRGs for the two isomers of 1,2 DCE.

The contaminant TCE is the other COC in the Paluxy aquifer. TCE is a carcinogen and has a published MCL of 5.0 $\mu\text{g/L}$ and, therefore, a PRG based on the MCL would be 5.0 $\mu\text{g/L}$. A PRG based on human health risk must consider the multiple exposure pathways for TCE. Using EPA guidance for developing PRGs (EPA 1991a) and results of the BRA, a PRG of 3.0 $\mu\text{g/L}$ was calculated for TCE in the Paluxy aquifer, considering the three exposure pathways for TCE. The PRG that considers multiple pathways will be used since it is lower than the PRG based on the MCL. The final remediation goal may be based on the MCL or the PRG and will be established in the record of decision (ROD). The supporting calculations for the PRG, based on multiple exposure pathways, can be found in Appendix C. PRGs for the Paluxy aquifer are presented in Table 2-3.

Table 2-3 Preliminary Remediation Goals for Paluxy Aquifer

Area	COC	PRG	Exposure Pathway/Threat
Paluxy aquifer	TCE	3.0 $\mu\text{g/L}$	ingestion, inhalation during showering, dermal exposure during showering
	<i>cis</i> -1,2-DCE	70.0 $\mu\text{g/L}$	ingestion
	<i>trans</i> -1,2-DCE	100.0 $\mu\text{g/L}$	

Using the PRGs developed above, the RAO for the Paluxy aquifer is to prevent human exposure from ingestion, inhalation during showering, and dermal exposure from showering to TCE concentrations exceeding 3.0 $\mu\text{g/L}$ and to DCE concentrations exceeding 70 $\mu\text{g/L}$ for *cis*-1,2-DCE and 100 $\mu\text{g/L}$ for *trans*-1,2-DCE. It should be noted that DCE is a degradation product of TCE and is very similar in treatment response. Therefore, any remedial response for TCE also would achieve the RAO for DCE.

2.3.1.2 East Parking Lot Plume

RAOs are being developed for the East Parking Lot Plume because contamination in the Upper Zone flow system is the source of contaminant migration into the Paluxy aquifer. Contamination of the Paluxy aquifer occurs in the Window Area of the East Parking Lot Plume where there is hydraulic connection between the two aquifers. Because the two aquifers are hydraulically connected, the ability to meet PRGs for the Paluxy aquifer is directly affected by contaminant levels in the Window Area. Therefore, a PRG will be based on contaminant levels in the Window Area that do not cause contaminant levels in the Paluxy aquifer to exceed its PRG.

The Upper Zone flow system within the boundaries of Plant 4 and CAFB is not considered a current or potential source of drinking water because of the low yield of the aquifer, readily available drinking water from a municipal source or the regional Paluxy Aquifer, and the ability to control use of the Upper Zone groundwater. Because the Upper Zone flow system is not a drinking water source, a PRG based on MCLs or risk from using the Upper Zone groundwater is not being considered.

One way of relating contaminant levels in the Window Area with contaminant levels in the Paluxy aquifer is to use a mixing equation that determines the allowable TCE concentration in the Window Area based on the allowable TCE concentration in the Paluxy aquifer. Using the Paluxy aquifer PRG of 3 $\mu\text{g/L}$, the Window Area PRG would be 250 $\mu\text{g/L}$. If the MCL of 5 $\mu\text{g/L}$ is used as the final cleanup level for the Paluxy aquifer, the Window Area cleanup level will be 400 $\mu\text{g/L}$. The Window Area has been defined as the area within 250 feet of well W-149. This is the approximate area where the Walnut Formation is thinnest and forms a sump. The supporting calculations for the mixing equation can be found in Appendix C.

The East Parking Lot Plume is strongly suspected of having DNAPL and the ability to meet the PRG for dissolved TCE in the Window Area is directly affected by the presence of DNAPL. Although DNAPL has not been directly found in the East Parking Lot, it is suspected because of continued high dissolved TCE concentrations and because the plume runs diagonal to the groundwater flow direction.

The presence of DNAPL also is significant because it affects dissolved TCE concentrations in surface waters on CAFB. The East Parking Lot Plume migrates to the east where it recharges surface waters on CAFB. The main surface water system on CAFB is Farmers Branch Creek and its tributaries. TCE has been detected in Farmers Branch Creek and its tributaries, although, concentrations are below human health or ecological risk threshold values. However, the continued presence of DNAPL could result in increased concentrations of TCE that may exceed risk thresholds.

Considering the impacts of the presence of DNAPL in the groundwater, removal of the DNAPL is an objective for the entire East Parking Lot Plume. However, a quantitative PRG that directly shows whether DNAPL has been removed is difficult to establish. The indicator that will be used to determine whether DNAPL has been removed is attainment of dissolved phase TCE concentration of less than 10,000 $\mu\text{g/L}$, one percent of TCE's solubility in water. Recognizing that dissolved TCE concentrations will increase after extraction has stopped, remediation will continue until TCE concentrations drop below 7,500 $\mu\text{g/L}$. Dissolved phase TCE concentrations will be expected to increase for some time, potentially 5 to 10 years, before they begin to decrease. However, if dissolved TCE concentrations increase to levels above 10,000 $\mu\text{g/L}$, remediation would begin

immediately and continue until levels drop below 7,500 $\mu\text{g/L}$ again. Monitoring of TCE levels would be done during and after remediation.

Another consideration for the Upper Zone groundwater is contamination that may move offsite. Within the Plant 4 and CAFB boundaries prevention of the Upper Zone groundwater for drinking water use is considered reasonable. However, prevention of using the Upper Zone groundwater for drinking water use off federal boundaries is not considered reasonable. Therefore, MCLs are a PRG for Upper Zone groundwater contamination that moves off federal boundaries.

Three PRG have been developed for the Upper Zone groundwater, depending on location, and are summarized in Table 2-4.

Table 2-4 Preliminary Remediation Goals for the East Parking Lot Plume

Area	COC	PRG	Exposure Pathway/Threat
Window Area	TCE	250 $\mu\text{g/L}$	hydraulic connection to drinking water aquifer (see exposure pathways for Paluxy aquifer)
DNAPL Areas: - Building 181 - Window Area	TCE	dissolved TCE concentrations less than 10,000 $\mu\text{g/L}$	dissolution of DNAPL and then migration of dissolved TCE to areas that cause risk
Outside Boundaries of Air Force Plant 4 or CAFB	TCE DCE	5 $\mu\text{g/L}$ for TCE, 70 $\mu\text{g/L}$ for <i>cis</i> -1,2-DCE, and 100 $\mu\text{g/L}$ for <i>trans</i> -1,2-DCE	potential for use of groundwater as drinking water

The RAOs for the East Parking Lot Plume that consider the exposure pathways, COCs, and PRGs are:

- 1) Prevent TCE concentrations in the Window Area of the East Parking Lot Plume from causing allowable TCE concentrations to be exceeded in the Paluxy aquifer. An allowable TCE concentration for groundwater in the Window Area is 250 $\mu\text{g/L}$, based on a PRG in the Paluxy aquifer of 3 $\mu\text{g/L}$.
- 2) Remove DNAPL in the East Parking Lot Plume so as to prevent dissolved TCE concentrations from exceeding cleanup levels for the Window Area or risk thresholds for surface waters on CAFB. Removal of DNAPL will be demonstrated by TCE concentrations of less than 10,000 $\mu\text{g/L}$.
- 3) Prevent Upper Zone groundwater with contamination above MCLs from migrating Air Force Plant 4 or CAFB boundaries.

The BRA found that contamination in the West Plume and North Plume of the Upper Zone flow system does not exceed human health or ecological risk thresholds for a present and future industrial land-use scenario. However, contamination in the Paluxy aquifer is present under the West Plume in the area of Landfill No. 3. This contamination is suspected to be caused by poor construction of the Paluxy well P-22, which allows TCE contaminated groundwater to migrate down the casing of the well to the Paluxy aquifer. This source of contamination can be stopped by properly abandoning well P-22. Remedial alternatives for the Paluxy aquifer will include this area of contamination.

As described in previous sections, the Air Force is pursuing voluntary actions to remove contaminants in the North Plume and West Plume. These voluntary actions will reduce risk levels below current levels. RAOs are not being developed for the North Plume and West Plume because contamination does not exceed risk threshold values. Because the contamination will remain in the groundwater for a period of time, continued monitoring will be required to ensure risk threshold values are not exceeded. Continued monitoring of North Plume and West Plume will be included in remedial alternatives for the East Parking Lot Plume.

2.3.2 Soil/Sediment

Remedial action objectives for contaminated soil and sediment generally are human health or ecological risk driven and not ARAR driven. Since Federal, State, or local chemical-specific ARARs for soil or sediment remediation were not discovered during the ARAR evaluation, human health and ecological risk-based PRGs were developed for contaminated soil at Plant 4.

Soil contamination exists at sites other than those presented below, but the BRA found that the concentration of these contaminants did not exceed risk threshold values. Remedial alternatives will be developed for sites listed below. Sites not listed will not have remedial alternatives developed.

2.3.2.1 Landfill No. 1

The BRA concluded that BAP concentrations exceeded the human health risk threshold value. The contaminant BAP is a carcinogen and human health risk was calculated at 1.6×10^{-6} ILCR, above the threshold value of 1.0×10^{-6} ILCR. The risk-based PRG for BAP was calculated to be 1.0 mg/kg, based on the occupational ingestion of contaminated soil exposure pathway.

Landfill No. 1 soil sampling results indicate the presence of BAP in concentrations exceeding the PRGs, as shown in Figure 1-25. All instances of BAP exceeding the PRGs are from the shallowest sample depths. Since Landfill No. 1 is located underneath a paved parking lot, the BAP present in shallow samples is suspected of being a result of asphalt paving fragments and not waste disposal practices. Also, the risk level calculated for BAP was 1.6×10^{-6} , within the acceptable risk range of 1.0×10^{-4} to 1.0×10^{-6} . Consequently, the BAP in Landfill No. 1 will not be targeted for potential remedial action.

2.3.2.2 Landfill No. 4

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Landfill No. 4 soil sampling results showed BAP present in concentrations exceeding its PRG of 1.0 mg/kg. Unlike Landfill No. 1, Landfill No. 4 is not covered with pavement. Also, samples containing BAP were found at greater depths in Landfill No. 4 than in Landfill No. 1. Therefore, the BAP present in Landfill No. 4 is presumed to be a result of waste disposal practices and consequently will be targeted for potential remedial action. The RI identified a volume of 32,000 cubic yards of VOC and semi-VOC contamination. It is assumed that BAP is mixed throughout this 32,000 cubic yards of soil. The risk level calculated for BAP in the landfill is 1.6×10^{-6} . An RAO for Landfill No. 4 will be to prevent ingestion of BAP contaminated soils with concentrations exceeding a PRG of 1.0 mg/kg.

Based on ecological risk, concentrations of arsenic, cadmium, and copper exceeded threshold values in Landfill No. 4 soils (Figure 2-1). PRGs developed for these contaminants are based on ecological risk threshold values that considered exposure to mice. The PRGs for arsenic, cadmium, and copper are 29.1 mg/kg, 132 mg/kg, and 563 mg/kg, respectively. The area where the PRGs are exceeded is along the top of Landfill No. 4 within the top five feet of soil. The RAO for Landfill No. 4 is to prevent the exposure of mice to arsenic, cadmium, and copper at levels which exceed 29.1 mg/kg, 132 mg/kg, and 563 mg/kg, respectively.

2.3.2.3 Landfill No. 3

Based on ecological risk, concentrations of copper, lead, and zinc exceeded threshold values in Landfill No. 3 soils (Figure 2-2). PRGs were developed for these contaminants based on ecological risk threshold values that considered exposure to mice. The PRGs for copper, lead, and zinc are 563 mg/kg, 2,000 mg/kg, and 1,000 mg/kg, respectively. The area where the PRGs are exceeded is along the west slope of Landfill No. 3 within the top two feet of soil. The RAO for Landfill No. 3 is to prevent exposure to mice from copper, lead, and zinc at levels which exceed 563 mg/kg, 2,000 mg/kg, and 1,000 mg/kg, respectively.

2.3.2.4 Meandering Road Creek

Based on ecological risk, concentrations of silver in Meandering Road Creek sediments and the sediments in Lake Worth exceeded threshold values (Figure 2-3). The PRG for silver is 1.0 mg/kg based on potential toxicity to aquatic organisms. Concentrations of silver exceeded 1.0 mg/kg in Meandering Road Creek sediments at one location and in the inlet to Lake Worth. For purposes of the FS, the inlet to Lake Worth will be considered part of Meandering Road Creek. The RAO for Meandering Road Creek is to prevent exposure of aquatic organisms to concentrations of silver above 1.0 mg/kg in the Meandering Road Creek sediments.

2.3.2.5 Building 181

As the result of leaks from TCE storage vessels in Building 181, TCE is in the vadose zone under the building. Because the building completely covers the vadose zone where contamination is present, exposure to the soil does not occur. However, some of the TCE in the vadose zone migrates down to the groundwater. Once the TCE is dissolved in the groundwater, it migrates to the Window Area where contamination of the Paluxy aquifer occurs because of hydraulic connection between the aquifers. Therefore, remedial alternatives for the TCE in the vadose zone under Building 181 will be developed.

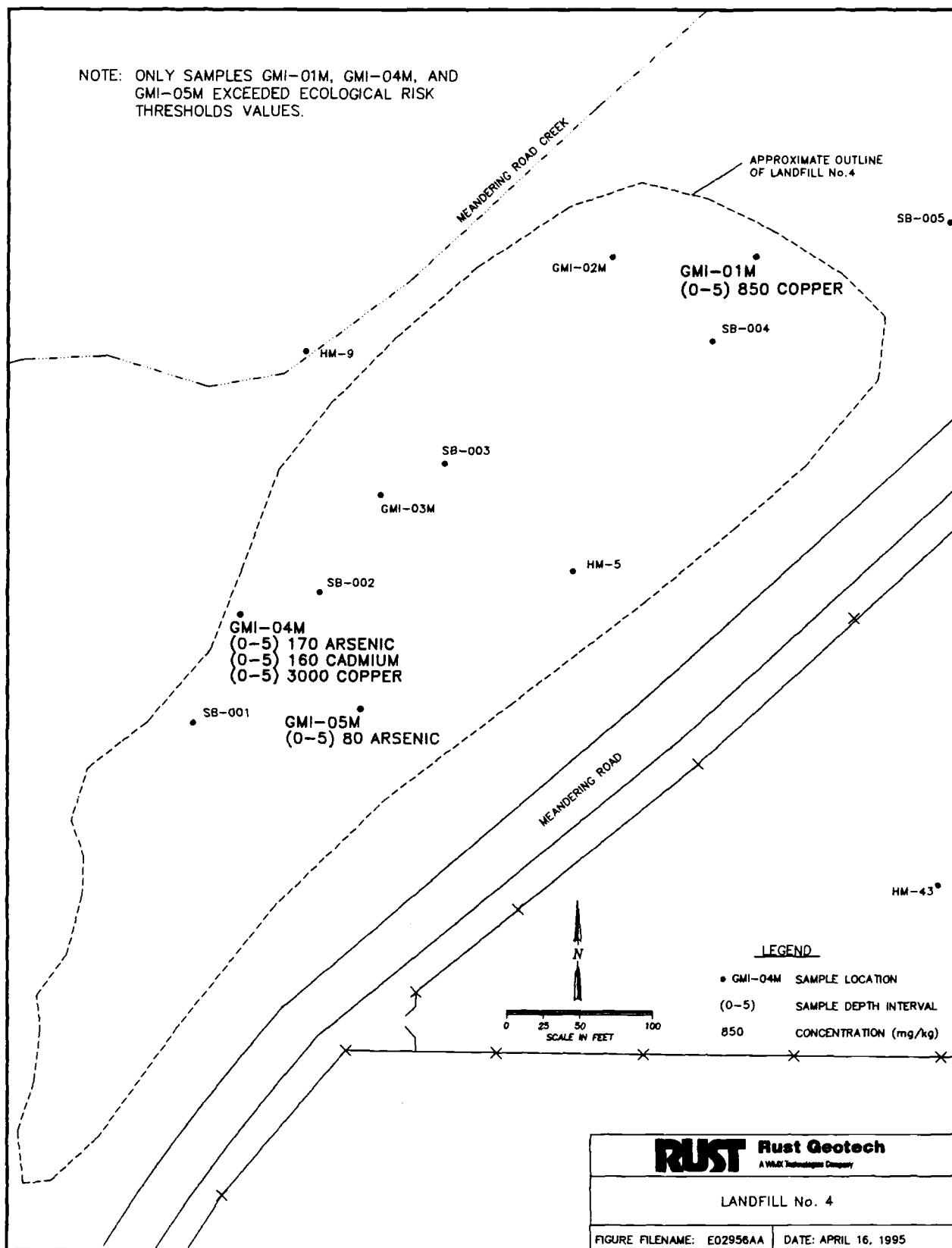


Figure 2-1. Landfill No. 4 Metals Contamination that Exceeds Ecological Risk Thresholds.

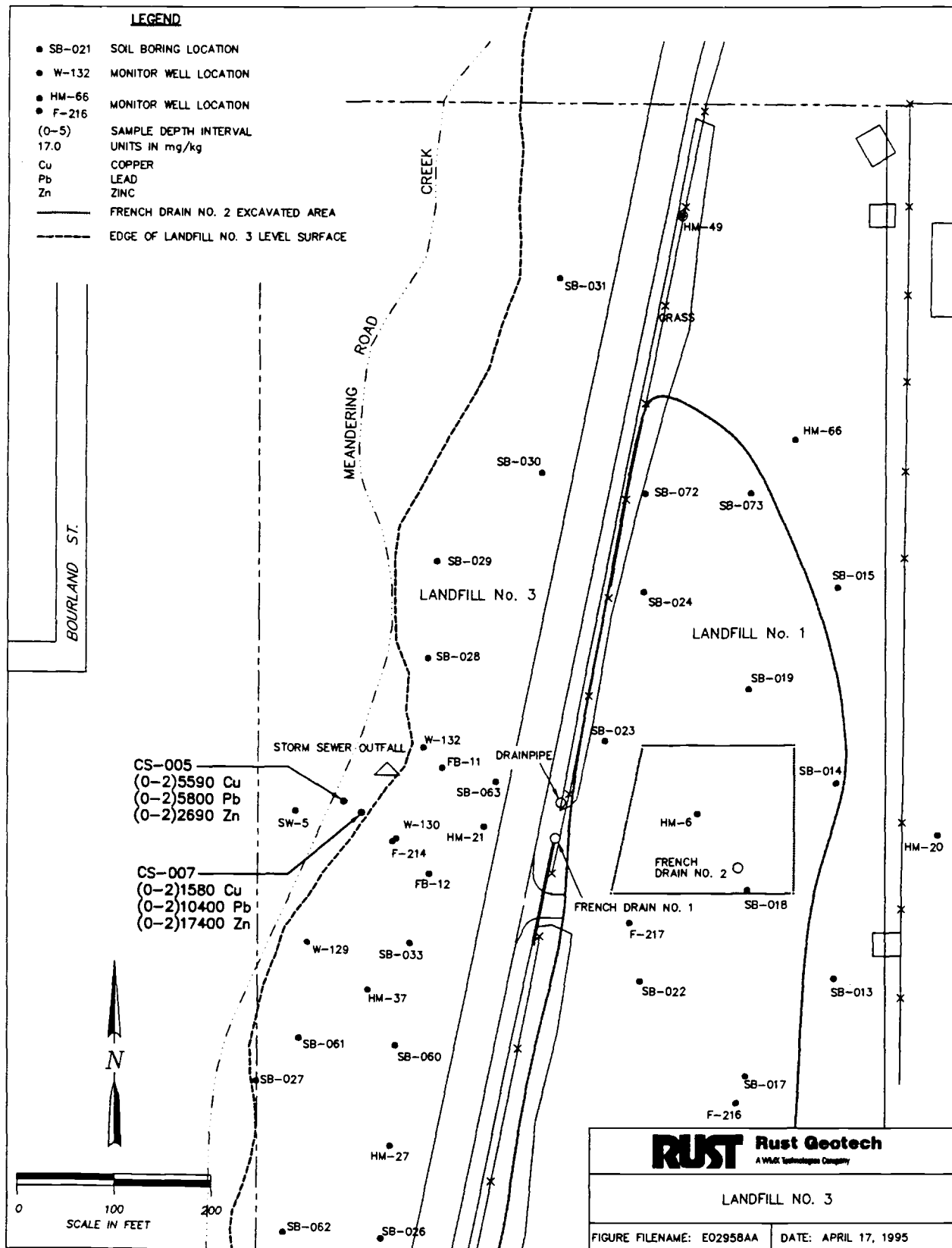


Figure 2-2. Landfill No. 3 Soil Samples that Exceeded Ecological Risk Threshold Values.

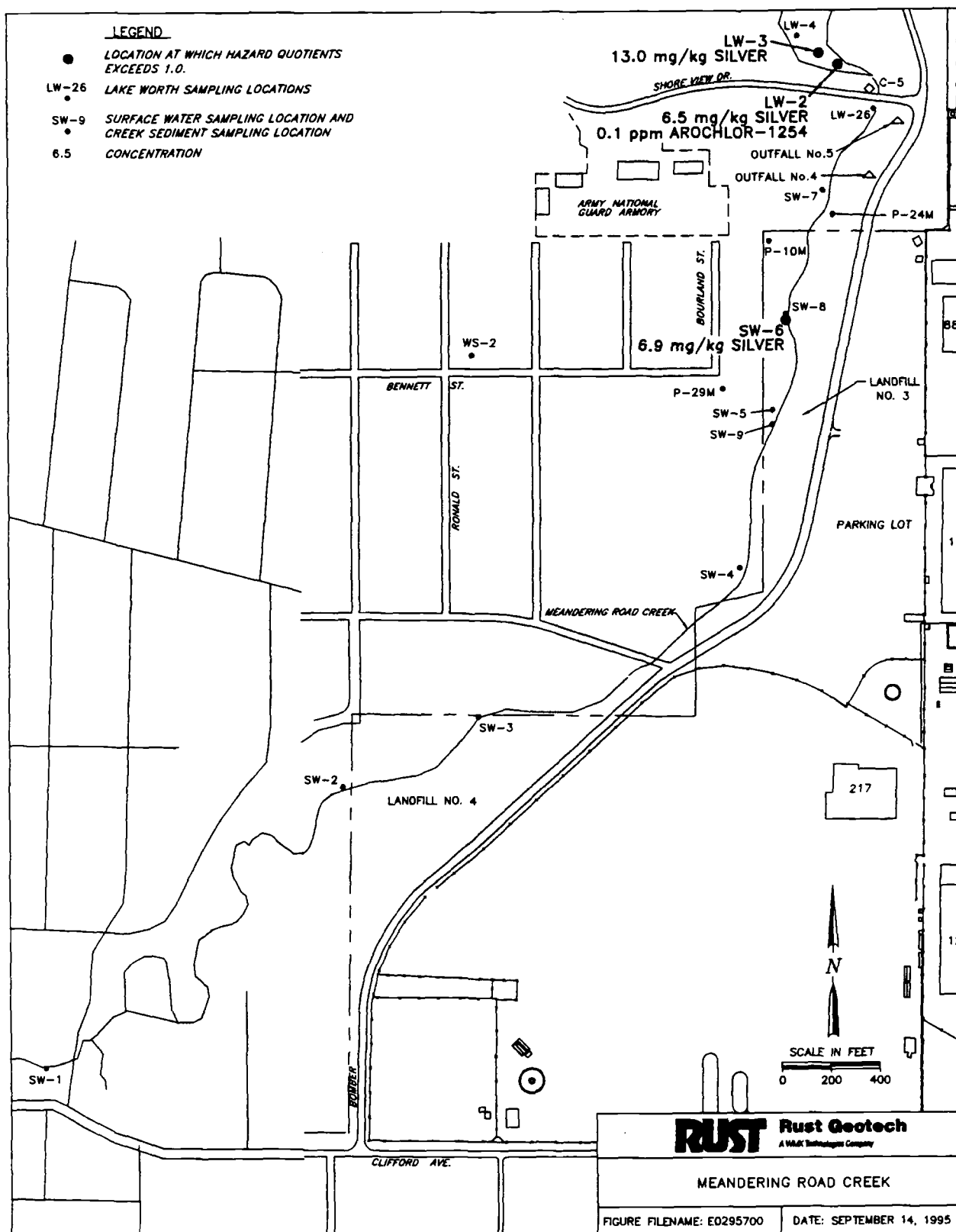


Figure 2-3. Locations and Contaminants in Sediment for which Hazard Quotients Exceed 1.0.

The PRG for the Upper Zone groundwater under Building 181 is removal of DNAPL as demonstrated by dissolved concentrations of less than 10,000 $\mu\text{g/L}$. This also is the allowable level for the concentration of TCE in leachate from the contamination in the vadose zone. However, 10,000 $\mu\text{g/L}$ is the highest allowable level in the groundwater (and leachate). To assure that peak levels of groundwater contamination are not caused by leachate from TCE in the soil, one-half this level (5,000 $\mu\text{g/L}$) will be used as the allowable leachate concentration from TCE in the vadose zone under Building 181.

To determine an allowable concentration for TCE in the soil that will not produce a leachate greater than 5,000 $\mu\text{g/L}$, an equilibrium soil/water partition equation was used (Dragun 1988). This equation resulted in an allowable soil concentration for TCE of 11.5 mg/L. The calculation is found in Appendix C. Therefore, the RAO for Building 181 is to prevent TCE concentrations in the soil from exceeding 11.5 mg/kg.

2.3.3 Air

The BRA concluded that benzene, chromium, and TCE posed health risks that exceed the 1×10^{-6} threshold value through the "occupational inhalation of contaminated air" expose pathway. The contaminant concentrations used in the BRA to estimate the health risks were results of direct air sampling (rather than estimated from potential fugitive dust emissions). Two air sampling stations were employed, one on site and one off site. Measured concentrations of chromium and benzene appear to be independent of sampling location and wind direction. Both chromium and benzene were detected in all samples both on and off site. The conclusion suggested by these data is that the benzene and chromium present in the air is not a result of the Plant 4 CERCLA sites. Therefore, no RAOs are developed for benzene and chromium as air contaminants.

The measured TCE concentrations appear to correlate directly with the wind direction and the location of the on-site sampling location with respect to Building 181. However, the TCE in the air is most likely the result of ongoing Plant 4 operations and not a result of contamination at CERCLA sites on Plant 4. Therefore, no RAOs are developed for TCE as an air contaminant.

2.3.4 Surface Water

Contamination can reach surface waters through seeps from groundwater. Discharges to surface waters can also occur in the form of storm water runoff and runoff of construction water, should any be required. There is a potential for introducing contaminants to the surface waters should the runoff come in contact with contaminated soil. Typically, run-on and runoff control systems are used during construction activities to minimize contact with contaminated soil areas. The BRA examined dermal exposure while swimming as a credible exposure pathway to surface water. The results were significantly lower than the health risk threshold for both carcinogens and non-carcinogens. Also, the BRA states that none of the surface-water samples collected to date exceeded the ambient water quality criteria. Therefore, no specific remedial action objectives are identified.

2.4 General Response Actions

2.4.1 Groundwater

General response actions for groundwater contamination can be divided into the four broad categories listed below. Various options are available within each of these categories. Many remedial actions combine technologies from two or more of the categories to provide an effective remediation.

1. No-Action
2. Institutional Controls
3. Containment
4. Collection/Treatment/Discharge

A no-action response means no further work would be performed to reduce contaminant levels or sever the exposure pathways but it can include monitoring. A no-action alternative must be included as a comparison to the other options.

Institutional control response actions may rely on the natural ability of groundwater to lower contaminant concentrations through physical, chemical, and biological processes until cleanup levels are achieved (EPA 1988b). Ordinarily, some degree of monitoring is conducted to provide assurance that the situation is improving with time and to detect any contamination excursions, should they occur. An institutional control for groundwater remedial actions may include measures for controlling future groundwater use patterns, such as deed restrictions, fencing, and other security measures to prevent access to the contaminated medium.

Containment can be accomplished using methods such as slurry walls that intercept the water for diversion or treatment. Containment can also be accomplished hydraulically by using extraction wells to arrest the migration of contaminated groundwater.

Collection/treatment/discharge encompasses removing the contaminated groundwater from the subsurface, treating contaminants in the groundwater and discharging the groundwater. Collection of the groundwater would come from strategically placed extraction systems such as wells or trenches. The type of extraction system is determined primarily by the heterogeneity of the strata and the hydraulic conductivity of the aquifer.

Because DNAPL is suspected at the site, enhanced DNAPL recovery methods that target the DNAPL source will be examined. Two such methods are steam and surfactants. Both methods have the potential to increase mobility and enhance solubility. Steam primarily enhances the mobility of DNAPL and surfactants primarily increase the solubility which allows the DNAPL to be recovered through a dissolved contaminant collection system.

Treatment technologies include in-situ treatment such as bioremediation and ex-situ treatment technologies. There are many ex-situ options available for treatment of groundwater, including activated carbon adsorption, air stripping, ultraviolet/ozone chemical oxidation, and bioremediation. Innovative technologies are those treatment technologies which have been demonstrated but require further field testing.

Options for discharging groundwater are limited. In some cases, it is possible that the POTW may accept untreated water but this is rare. Other choices include discharging treated water to a POTW, to surface water, or underground. The voluntary actions at the site have used discharge to a POTW and discharge to surface waters.

2.4.2 Soil/Sediment

General response actions for soil or sediment normally fall into the five categories listed below.

1. No-Action
2. Institutional Controls
3. Containment
4. Treatment
5. Removal/Disposal

The no-action option usually includes monitoring, and generally refers to leaving a site as is without further remedial measures.

Institutional controls are deed restrictions, fencing, and other limitations that prevent human exposure to contaminated soils by controlling access to contaminated areas. Continued site monitoring may also be included as an institutional control.

Containment actions employ capping, vertical barriers, and horizontal barriers. The barriers prevent water infiltration and subsequent contaminant leaching. They also prevent erosion from wind and water.

Treatment options after excavation include incineration, solidification or stabilization, and a variety of new technologies such as soil washing.

2.5 Estimation of Contaminated Volumes

2.5.1 Groundwater Volumes

Groundwater contamination at Air Force Plant 4 involves an aquifer and a flow system, the Paluxy aquifer and the Upper Zone flow system. Contamination in the Paluxy aquifer is found in two separate plumes, an East plume that originates under the East Parking Lot and a West plume found under Landfill No. 3. The contaminated volume of groundwater in the Paluxy Upper Sand is estimated at 3.8×10^7 gallons and the contaminated volume of groundwater in the Paluxy West plume is estimated at 5.4×10^6 gallons. The calculations for the volume of contaminated groundwater are found in Appendix C.

Contamination in the Upper Zone flow system is found in three plumes, the East Parking Lot Plume, the North Plume, and the West Plume. The East Parking Lot Plume is the largest contaminated groundwater plume at Plant 4. The volume of TCE in the East Parking Lot Plume is unknown. In June 1991, an estimated 20,000 gallons of TCE leaked from holding tanks in Building 181. However, a TCE plume was already present under the building when this spill occurred. An estimate of the volume of TCE in the dissolved or sorbed phase in the East Parking Lot Plume is approximately 4,500 gallons. The rest is suspected to be present in the vadose zone under

Building 181 and as DNAPL migrating in the paleochannel under Building 181 and the East Parking Lot, although precise location of the DNAPL is not known.

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The Upper Zone groundwater in the West Plume and North Plume is contaminated but contamination levels do not pose an unacceptable risk to human health or the environment. Therefore, quantities of contaminated groundwater are not being estimated for these groundwater areas.

2.5.2 Soil Volumes and Areas

Landfill No. 4 has soil contaminated with BAP that exceeds the 1×10^{-6} ILCR threshold. The volume of soil contaminated with BAP that is targeted for possible remedial action is 32,000 cubic yards (yd^3). In addition, Landfill No. 4 has an estimated 555 yd^3 of soil contaminated with arsenic, cadmium, and copper that exceed ecological risk threshold values. The soils contaminated with arsenic, cadmium, and copper are not the same soils that are contaminated with BAP. Therefore, the total amount of contaminated soil at Landfill No. 4 is 32,555 yd^3 .

Landfill No. 3 has soil contaminated with copper, lead, and zinc that exceed ecological risk threshold values. The estimated volume of contaminated soil at Landfill No. 3 is 185 yd^3 . The sediments in Meandering Road Creek are contaminated with silver at levels that exceed ecological risk threshold values. The estimated volume of sediments contaminated with silver is 277 yd^3 .

The soils in the vadose zone under Building 181 are contaminated with TCE. The TCE contamination under Building 181 is difficult to characterize and is, therefore, not well defined. The contamination around the perimeter of Building 181 is low, so contaminated soil is assumed to be limited to the area under the building. Contamination is assumed to be within a surface area of approximately 75,000 square feet (ft^2). The average depth of the vadose zone in this area is approximately 25 feet, giving a volume of soil with TCE contamination at approximately 1,875,000 cubic feet (69,440 yd^3), although TCE contamination in this volume is not continuous.

2.6 Identification and Screening of Technology Types and Process Options

A large variety of technology types and process options are available for consideration in environmental remediation. Many of these processes are still in the development or demonstration stage. Others are suitable only for specific limited applications or involve costs much greater than those for another, equally acceptable alternative.

This section of the FS identifies available technology types and process options for contaminated areas that may require remediation. This section also performs an initial screening of process options to remove from further consideration those options that are unsuited for Plant 4. The screening will consider the Paluxy aquifer separately from the Upper Zone flow system. The process options that pass the screening will then be assembled into alternatives in Section 3.

The primary criteria used for screening in this section are technical implementability and effectiveness. The effectiveness evaluation for each technology type and process option will focus on: 1) the potential effectiveness of process options in handling the estimated areas or volumes of media and satisfying the identified remedial action objectives; and 2) the proven reliability of the process with respect to the contaminants and conditions at Plant 4 (EPA 1988a). The implementability evaluation focuses on the technical and administrative feasibility, with the primary emphasis on technical feasibility at this stage in the screening process.

2.6.1 Groundwater

This section screens technology types and process options for groundwater. Areas of groundwater that may require remediation are the dissolved TCE plume in the Paluxy aquifer and the dissolved TCE plume and suspected TCE DNAPL areas in the Upper Zone flow system. The process options include those identified in *Supplemental Review of Remedial Alternatives, Air Force Plant 4 and Carswell Air Force Base*, (Environmental Science & Engineering 1994b). Preliminary screening comments are made as to whether a process option is applicable and will be considered further, or not applicable and will not be further considered.

No-Action

The no-action technology means that no actions would be taken to limit or control exposure to contaminants or treat the contaminants. A no-action response could be selected for any of the groundwater areas. The only action that would be taken is monitoring to detect movement of the contaminant plume. The no-action alternative is required to be retained by the NCP for consideration. Also, Plant 4 property is expected to remain under the jurisdiction of the federal government for the indefinite future. CAFB property is currently under the jurisdiction of the federal government but future land-use is not as well known. Deed restrictions that limit groundwater use could affect future uses on CAFB.

Institutional Controls

Institutional controls considered are access restrictions, deed restrictions, monitoring, tying into an existing municipal line, and developing a new private system.

Access Restrictions: Access restrictions already exist at Plant 4 as part of the administration of the base. The Plant 4 property is expected to remain under the jurisdiction of the federal government for the indefinite future. If the contaminant plume in either the Paluxy aquifer or the Upper Zone flow system migrates off-site, access restrictions would be very difficult to implement. For this reason, access restrictions are not being retained for either groundwater area.

Deed Restrictions: In most states deed restrictions are a method of controlling land-use and groundwater-use after the sale of a property. In Texas a deed "notice" can be imposed on a property. Also, the Plant 4 property is expected to remain under the jurisdiction of the federal government for the indefinite future. Deed restrictions are being retained as applicable for the Upper Zone flow system only.

Monitoring: Groundwater monitoring is generally performed by periodically sampling a series of wells drilled at locations both up gradient and down gradient of the area to be monitored. The wells are constructed to avoid cross-contamination between aquifers and to permit collection of water at specified depths within the groundwater. Groundwater monitoring may be used to confirm that the no-action alternative remains appropriate because the conditions remain the same and that the plume is not migrating off-site, to confirm that groundwater contamination levels remain low after groundwater remediation, to gather data for use in design of remedial actions, or to determine the efficacy of a particular remedial action. This will be retained for both the Paluxy aquifer and the Upper Zone flow system.

Tieing into Existing Municipal Line: This would involve locating a nearby municipal system to obtain a potable source of water. The nearby municipal system must be capable of supporting the additional demand of the White Settlement population (13,508 people as of the 1980 census). If the system is sufficiently expandable, agreements must be signed between the two communities before construction can occur. A new distribution system would then have to be constructed. Tieing into an existing municipal line is more complex and difficult to implement than development of a new private system. This option will be dropped from further consideration.

Development of New Private System: Drilling into the Travis Peak/Twin Mountains aquifer below the Paluxy allows White Settlement to maintain their current water treatment and distribution system. The wells, properly constructed, would provide a safe, potable supply. This alternative would offer a safe water source. It will be retained for the Paluxy dissolved plume as it would meet RAOs by itself and is effective.

Containment

Containment is generally used to slow or stop the spread of a contaminant plume to prevent human exposure to the contaminants. In some cases, natural attenuation may gradually achieve cleanup levels within the area. Conditions that generally favor the use of a containment alternative include the following (EPA 1988b):

- Groundwater that is naturally unsuited for consumption
- Low mobility contaminants
- Low aquifer transmissivity
- Low concentrations of contaminants
- Low potential for exposure
- Low projected demand for future use of the groundwater

Two types of physical containment, barriers and capping, and hydraulic containment are discussed below.

Barriers

Sheet Piling: Sheet pile cutoff walls consist of steel walls similar to those used in highway construction as retaining walls. Sheet piling can be used as a barrier wall in situations where the depth to bedrock is no more than 40 feet. The wall is installed around a migrating plume to contain the contaminants. This type of wall is difficult to install in rocky soil, is subject to corrosion problems and rising groundwater levels, and is usually considered temporary. Sheet piling is appropriate for some areas of Plant 4 but fill areas could cause problems due to the presence of construction rubble. Sheet piling will not be retained as an option primarily due to its temporary usefulness.

Slurry Walls: Slurry walls are constructed by injecting a clay slurry into a trench as a continuous wall extending from the ground surface to a near-impermeable layer below the contamination, such as bedrock. They provide two functions: to reduce or stop downstream migration and to limit the extraction quantity. Slurry walls have been proven effective over the short-term, but their long-term effectiveness is not known. This option is ineffective for the Paluxy aquifer but shall be retained for Upper Zone flow system.

Capping

Capping: Capping a contaminated area consists of installing a near-impermeable cover over a contaminated area to prevent infiltration of surface water into the contaminated area, effectively removing one mechanism by which contaminants are mobilized into groundwater. Many different types of caps are used, including clay, asphalt, and concrete. The majority of the site is already covered and this does not limit groundwater flow. This will not be retained.

Hydraulic Containment

Hydraulic Containment: Instead of installing an impermeable barrier, clean water is injected or extracted from strategically placed wells to prevent further migration or to alter groundwater flow direction and velocity. In the case of Plant 4, the plume is too large to effectively manage with this technology. It will not be considered.

Collection/Treatment/Discharge**Collection**

Vertical Wells: This option uses a series of vertical groundwater extraction wells installed around a contamination plume in a pattern that changes the normal flow of the groundwater in that area, preventing migration of the plume. Another variation is to place wells upgradient of the plume and inject uncontaminated water to push the plume to capture points. The vertical well extraction option will be retained.

Horizontal Wells: Horizontal extraction wells are most appropriate in highly permeable, coarse, homogeneous aquifers. Their use is the same as vertical wells but with some limitations. It is also not advisable to install these wells in areas with numerous underground utilities without a detailed utilities location study. This option will be retained.

Interceptor Trench: An interceptor trench could be used to cut off further dissolved contaminant migration to the Window Area. The trench would be located close to the Window Area and could be effective at limiting contamination that reaches the Window Area. An interceptor trench would serve the same function as a slurry wall. An interceptor trench would require active groundwater extraction and treatment to be effective. This option will be retained.

Enhanced Removal

Surfactants: Surfactants can increase the solubility and decrease the interfacial tension of a DNAPL/water mixture driving it into solution. The solubilized DNAPL can then be removed by conventional means such as pumping. It is one of the few treatments that targets DNAPL. This will be retained for the suspected DNAPL area in the Upper Zone flow system.

Steam: Steam decreases the viscosity and also volatilizes DNAPL. The dissolved portion can be removed by conventional pumping methods while the mobile DNAPL must be intercepted. A thorough understanding of the strata is necessary for steam to be effective because discontinuous dense lenses may allow the mobile and volatilized DNAPL to horizontally migrate faster than recovery methods can remove them, causing greater contamination. The strata at Plant 4 is very heterogeneous and, therefore, steam will not be considered.

Treatment

Physical Treatment

Air Stripping: Air stripping can be used as part of a pump and treat system to remove VOCs such as TCE and its degradation products from dilute aqueous waste streams. The contaminants are transferred to the air stream, which may require further treatment to prevent an excessive release of the contaminants to the atmosphere. Various types of air strippers are available with removal efficiencies ranging from 50 percent to greater than 99 percent. Air stripping is not appropriate for low volatility compounds, high solubility compounds, metals, or inorganics (EPA 1986). Air stripping is appropriate at Plant 4 for the VOCs present in the Upper Zone and Paluxy dissolved. Air stripping would also work with extracted groundwater that contains surfactants.

Carbon Adsorption: Carbon adsorption is a process in which molecules are attracted to and then held at the surface of granulated activated carbon. It is effective for a variety of organic compounds. Contaminated water is pumped through carbon beds. The primary design criteria for carbon systems are surface loading rate and bed contact time. Spent carbon may be disposed as a hazardous waste or shipped off site for regeneration. Activated carbon is a potentially effective option for the contaminated groundwater at Plant 4, especially as a polishing step that would follow a treatment such as air stripping. Carbon adsorption will be retained for further evaluation of Upper Zone dissolved and Paluxy dissolved plumes.

Crushed Peat Adsorption: Crushed peat has been shown to have properties similar to those of granulated activated carbon. Additionally, it has been shown to be effective in removing inorganics such as arsenic, chromium, selenium, uranium, and sulfate from solution (Longmire and Thomson 1990). However, the available adsorptive surface area per unit mass is two orders of magnitude less than that of carbon (Longmire and Thomson 1990). Crushed peat may be an effective option for the contaminated groundwater at Plant 4; however, the available engineering data is not sufficient to assess the performance of crushed peat adsorption to the level necessary for realistic comparison to better developed adsorptive technologies, i.e. activated carbon. Therefore, this option will be dropped from further consideration.

Ultrafiltration: Metal cations first combine with a chelating organic polymer. The resulting high molecular weight compounds are then retained by a sieve. This process is not well understood and has been demonstrated only recently. It will, therefore, not be considered further.

Permeable Treatment Beds: A permeable treatment bed can be installed downstream of a migrating contaminant plume to treat groundwater as it passes through the treatment bed. A trench is dug across the path of the plume and an appropriate treatment medium is installed. Common media used in treatment beds include crushed limestone, activated carbon, glauconitic green sands, and synthetic ion exchange resins. Choice of the medium is based on the type of contaminants. Plugging or channeling of untreated water through the bed may occur. Permeable treatment beds are most applicable to inorganic contaminants, not to the organic contaminants of Plant 4. Therefore, this option will be dropped from further evaluation for application at Plant 4.

Reverse Osmosis: Reverse osmosis is a membrane separation technology that allows a solvent such as water to be removed from a solution containing solutes by using hydrostatic pressure to force the water through a semi-permeable membrane. The process is effective for aqueous metal wastes, PCB contaminated water, water with high biochemical oxygen demand (BOD) levels, insecticides,

herbicides, organic and inorganic contaminated groundwater. Suspended solids and oils must be removed prior to treatment to avoid plugging. Process residuals require further treatment such as dewatering followed by fixation. Reverse osmosis is traditionally a method for treatment of inorganics, although some organic removal has been successfully demonstrated (EPA 1986). However, the addition of TCE in the water stream may cause fouling of the membranes. Reverse osmosis will not be considered.

Oil/Water Separation: Emulsified, floating, or sinking oils can be removed from water with a variety of different types of equipment. Three common types are oil separators, centrifuge equipment, and dissolved air flotation processes. In general, all operate by causing oil or other immiscible liquids with different specific gravities to migrate to a particular area of the device where they can be collected. Dissolved organic contaminants would not be removed by these types of equipment. This option is applicable to the NAPL organic contaminants in the Plant 4 groundwater and shall be retained for Upper Zone source.

Evaporation Ponds: This involves pumping contaminated groundwater to a lined evaporation pond. Solar radiation evaporates the water and volatile compounds. The remainder is left in the pond where it can be removed or left in place and closed as a disposal site. Since this is an operating facility, the likelihood of operating such a project on-site is limited. This option shall be omitted.

Chemical Treatment

UV/Oxidation: This process oxidizes organic contaminants, such as TCE, DCA, and DCE, using ultraviolet (UV) light in combination with ozone and/or hydrogen peroxide. The end products of the oxidation reaction are carbon dioxide, water, and trace halides. UV/oxidation technology is used as part of a pump-and-treat system and has been proven to be effective in oxidizing a very broad range of organic compounds, including all those on the EPA's Priority Pollutant List (Ultrox 1989). The UV/oxidation process destroys contaminants and the EPA has stated a preference for treatment technologies that effectively destroy contaminants. This process has also been demonstrated and in use for commercial water treatment such as the Denver Zoo. This option shall be retained for further evaluation for the Upper Zone and Paluxy dissolved plumes.

Neutralization: This is a pH adjustment process. It can be used as a pretreatment method or a final waste treatment process (EPA 1986). It is also used as a technique for precipitating metals from solution. The pH is not a problem at Plant 4; therefore, this process is inappropriate.

Ion Exchange: Ion exchange involves the removal of anions and cations dissolved in dilute aqueous wastes by exchanging undesirable ions in solution for ions on the ion exchange resins. A wide variety of inorganic dissolved contaminants can be removed by a cation exchange column in series with an anion exchange column. Some organic acids and bases can also be removed. Ion exchange is most appropriate for low concentrations of dissolved and suspended solids because high concentrations would result in high costs for maintenance and resin regeneration. A concentrated toxic backwash stream is produced during resin regeneration. This backwash stream generally requires further treatment using other processes such as precipitation or evaporation (EPA 1986). There are more efficient methods to treat organics; this option shall be omitted.

Metal Enhanced In-situ Degradation: An in-situ wall of metal catalyst and sand is constructed across the contaminated plume flow path. As the chlorinated organics cross the catalyst, they are reduced to ionic components such as chloride, hydroxide and ferric iron. This technology has been attempted in

the laboratory and on a pilot scale as part of a university research project. More efficient methods exist to treat chlorinated organics. This option will not be considered.

Titanium Dioxide Photocatalytic Oxidation: The core of this treatment is a photocatalytic reactor containing a UV lamp with a titanium dioxide (TiO_2) catalyst sleeve. The UV light and TiO_2 generate hydroxyl radicals which oxidize chlorinated organics into carbon dioxide, water, and chloride. This technology has been tested on the pilot scale. However, oxidation rates were increased when hydrogen peroxide was added. This technology does not prove to be sufficiently different from UV/oxidation and will not be considered.

High Energy Electron Beam Irradiation: Accelerated electrons oxidize water molecules into electrons, hydrogen radicals, and hydroxyl radicals. These in turn, react with organic compounds to form non-toxic by-products such as carbon dioxide, water and salts. This technology is in the research stage but has shown success with TCE. It has not been tested full scale and will not be considered.

Ultrasonic Detoxification: Ultrasonic energy waves (high frequency sound) compress and expand the groundwater and its contaminants. During these activities, water would decompose into hydroxyl radicals (OH^\cdot) and hydrogen ions then to hydrogen peroxide and hydrogen. The hydrogen peroxide would oxidize the chlorinated compounds into carbon dioxide, water, and salts. No results exist for TCE and this technology has not been tested on a pilot or full scale. It will not be considered.

Precipitation: This involves the addition of appropriate chemicals or the adjustment of pH to cause inorganic contaminants to settle out of the groundwater. In most cases, this process would be done as an above-ground treatment in combination with a groundwater extraction system. In some cases, it may be possible to use precipitation as an in-situ treatment, but precipitation is not applicable for organics. Precipitation in an above-ground system also requires treatment/disposal of the hazardous residuals. This is not applicable to organics.

Biological Treatment

Ex-situ Bioremediation: Above ground bioremediation uses microorganisms to destroy or alter non-toxic hazardous waste compounds in groundwater. The water is pumped to treatment units called bioreactors along with nutrients and oxygen. The waste stream is held in the reactor for a prescribed amount of time and broken down into carbon dioxide and water. Two basic types of microbes can remediate TCE and its degradation products: aerobes and anaerobes. Research has shown that anaerobes can produce more toxic by-products such as vinyl chloride and DCA. Aerobes, however, produce only water and carbon dioxide. Bioremediation does not reliably produce high removal efficiencies for chlorinated compounds and, therefore, this process will not be retained.

In-situ Bioremediation: In-situ bacteria are nourished through injecting air and nutrients into the groundwater to enhance their growth. Unlike above ground bioremediation, this cannot be completely controlled such that all degradation is aerobic. Anaerobic degradation of chlorinated organics has in some cases, caused the production of more toxic compounds such as vinyl chloride. Knowledge of the degradation process within the Paluxy and Upper Zone flow systems is incomplete and, therefore, this option will not be considered.

In-situ Treatment

Air Sparging: Air is injected into the contaminated aquifer to increase the water and vapor velocity. It is commonly used in tandem with vapor extraction to enhance vapor removal. Like steam, air

sparging can mobilize contaminants beyond the capture zone if the strata is heterogeneous with dense, discontinuous lenses. This condition is common at Plant 4. This will not be considered.

Bio Sparging: Similar to air sparging. Nutrients are entrained with the airstream. This will not be considered for the reasons outlined in in-situ bioremediation and air sparging.

Discharge

On-Site Discharge

Deep Well Injection: This involves pumping groundwater out of the affected aquifer into another aquifer. Both aquifers, the Upper Sand and the Paluxy Formation, are contaminated because they communicate. The aquifer below the Paluxy, the Twin Mountain/Travis Peak Aquifer, is considered a potable aquifer and thus not acceptable as a reinjection location. As a result, this will be dropped from consideration.

Discharge to Receiving Waters: Water would be discharged to a local stream. As in deep well injection, the water must be treated prior to discharge. The nearest stream is the intermittent Meandering Road Creek, which discharges into Lake Worth. This in turn recharges the Paluxy Aquifer. With treatment, the water could be discharged to receiving waters and will be retained for further examination for Upper Zone and Paluxy dissolved plumes.

Off-Site Discharge

POTW: The system would send treated water to the local treatment facility. This will be retained for Upper Zone and Paluxy dissolved plumes.

Table 2-5 summarizes the general response actions, technology types, and process options considered for groundwater remediation. The table includes a description of the processes and preliminary screening comments about whether the process option is being retained for consideration.

2.6.2 Soil/Sediment

This section evaluates technology types and process options for contaminated soil and sediment areas. Preliminary screening comments are made as to whether a process option is applicable and will be considered further or not applicable and will not be further considered. Site-specific characteristics and remediation objectives will be used for the initial screening.

No-Action

The no-action response is used as a comparison to the other technologies listed. At some sites, the contamination levels and the associated risks are low enough that no remedial action is necessary to protect human health. In these situations, especially if the contaminants are low-toxicity organics, the no-action option may provide the lowest risk to human health and the environment. Exposure of workers during remediation is eliminated, and natural environmental processes would reduce contamination levels with time. The no-action option is retained for further evaluation and for comparative purposes.

Table 2-5 Technology Types and Process Options for Groundwater

General Response Action	Technology Type	Process Options	Description	Preliminary Screening Comments
No Action	None	Not Applicable	No actions to remove contamination or sever the exposure pathway	Required for consideration by the NCP as a baseline comparison
Institutional Controls	Access Restrictions	Access Restrictions	Physical limitations to prevent access to land and groundwater	Satisfies RAOs, but not practicable, not considered
		Deed Restrictions	Limiting land and groundwater use by subsequent owners	Satisfies RAOs, but not practicable, not considered
	Monitoring	Monitoring	Water monitoring using existing wells	Potentially applicable to all
	Alternative Water Supply	Tie into existing municipal line	Putting affected homeowners onto municipal water supply	Due to complexity, not considered
		Develop new private system	Locating another aquifer for commercial, potable use	Potentially applicable to Paluxy aquifer
Containment	Physical Containment: Barriers	Sheet Piling	Driving interlocking steel walls around contamination	Subject to corrosion, difficult to install with fill, cobbles in soil, not applicable
		Slurry Walls	Inject clay slurry in continuous trench around contamination	Potentially applicable to the Upper Zone
	Capping	Asphalt, Clay, Concrete, Synthetic	Install impermeable cover to prevent infiltration and contaminant movement	Not applicable
	Hydraulic Containment	Groundwater injection	Injecting clean water to hydraulically control the dissolved plume	Plume already huge, water needed too great, not considered
Collection/Treatment/ Disposal	Collection Technologies: Groundwater extraction	Vertical wells	Pump contaminated groundwater using vertical wells to remove contaminants from the aquifer	Potentially applicable to the Upper Zone and Paluxy
		Horizontal wells	Pump contaminated groundwater using horizontal wells to remove contaminants from the aquifer	Potentially applicable to the Upper Zone and Paluxy
		Interceptor trench	Intercept dissolved contaminants in the subsurface	Potentially applicable to the Upper Zone and Paluxy
	Enhanced Removal	Surfactants	Methods that enhance DNAPL recovery by altering DNAPL properties (primarily solubility and interfacial tension)	Potentially applicable to the Upper Zone

Table 2-5 (continued) Technology Types and Process Options for Groundwater

General Response Action	Technology Type	Process Options	Description	Preliminary Screening Comments
Collection/Treatment/Disposal	Enhanced Removal	Steam	Injecting steam into aquifer to mobilize DNAPL	Difficult to control in heterogeneous media, could spread contamination, not considered
	Treatment technologies: Physical treatment	Air stripping	Remove dissolved volatile organics from groundwater with air	Potentially applicable to the Upper Zone and Paluxy
		Carbon adsorption	Adsorb dissolved organic compounds onto granulated carbon	Potentially applicable to the Upper Zone and Paluxy
		Crushed peat adsorption	Adsorb dissolved organics compounds onto peat	Less efficient than carbon, not considered
		Ultrafiltration	Chelate metal cations with organic compounds before filtering	Relatively new, not considered
		Permeable treatment beds	Place a treatment trench downgradient of the plume	Difficult to control treatment, not considered
		Reverse osmosis	Use a membrane to separate contaminants and water	TCE may cause membrane fouling, not considered
		Oil/water separation	Separate emulsified, floating or sinking oils from water	Potentially applicable to the Upper Zone
		Evaporation ponds	Evaporation of water and some contaminants from a lined pond	Plant currently operating, there is a potential for exposure, not considered
	Chemical Treatment	UV/oxidation	Use ultraviolet light with ozone or hydrogen peroxide to destroy contaminants	Potentially applicable to the Upper Zone and Paluxy
		Neutralization	Precipitates out metals	Metals are not a problem, not considered
		Ion exchange	Use resins to remove ions from water	Not applicable
		Metal enhanced in-situ degradation	Dissolved organics are degraded as they cross in-situ permeable wall of metal catalyst	More efficient dissolved organic treatment exists, not considered
		Titanium dioxide photocatalytic oxidation	UV lamp with titanium dioxide catalyst oxidizes dissolved organics	More efficient dissolved organic treatment exists, not considered

Table 2-5 (continued) Technology Types and Process Options for Groundwater

General Response Action	Technology Type	Process Options	Description	Preliminary Screening Comments
Collection/Treatment/Disposal	Chemical Treatment (cont.)	High energy electron beam irradiation	High energy electrons break down dissolved organics into CO ₂ , water, and salts	More efficient dissolved organic treatment exists, not considered
		Ultrasonic detoxification	High frequency sound transforms dissolved chlorinated organics into non-hazardous compounds	More efficient dissolved organic treatment exists, not considered
		Precipitation	Adjust pH to cause inorganic contaminants to precipitate out of solution	Not applicable
	Biological treatment	Ex-situ bioremediation	Use microorganisms to destroy or alter contaminants	Not reliable for chlorinated compounds, not considered
		In-situ bioremediation	Use microorganisms to destroy or alter contaminants	Not considered because still in the development stage for chlorinated hydrocarbons
	In-situ treatment	Air sparging	Pump air into aquifer, volatilize dissolved organics	Difficult to control in heterogeneous media, could spread contamination, not considered
		Bio sparging	Pump air and nutrient into aquifer, volatilize and digest dissolved organics	Difficult to control in heterogeneous media, could spread contamination, not considered
	Discharge technologies: On-site Discharge	Discharge to surface water	Discharge treated water to local surface water	Potentially applicable for the Upper Zone and Paluxy
		Deep well injection	Discharge untreated water to non-potable aquifer	Aquifer below Paluxy is potable, not considered
	Off-Site Discharge	POTW	Send water to an off-site treatment facility	Potentially acceptable for all

Institutional Controls

Access Restrictions In some cases, access to controlled areas can be restricted, thus eliminating the hazards to the general public. This option is particularly effective in areas that are owned by a government agency with long-term control of the land. Since the identified exposed population to soil contaminants is the Plant 4 work force and not the general public, access restrictions would not be meaningful. This option shall be dropped from further consideration at Plant 4.

Deed Restrictions In most states deed restrictions can be imposed upon sale of a property. Such restrictions would be land-use and soil-use related with the intent of preventing inadvertent exposure to contaminants by subsequent owners of the property who may not be aware of the previous situations at the property. In Texas, a deed "notice" can be imposed on a property. Although the Plant 4 property is not expected to change hands in the future, this option shall be retained for further consideration.

Containment

Containment technology types that physically isolate contamination from the environment are barriers and caps. The movement of groundwater and surface water through the waste material and erosion are controlled, thus preventing migration of the wastes from the site. Containment is most often accomplished through the use of either a combination of subsurface barrier walls and impermeable caps, barrier walls, or caps singly. The barrier walls serve to prevent the movement of groundwater through the site, and the impermeable cap controls erosion and the infiltration of surface water. Capping will be retained as an option since it controls the two cited exposure pathways to soil contamination: ingestion and inhalation. Barriers will be dropped at this point since they do not control the relevant exposure pathways.

Treatment

Physical Treatment

Vitrification: In-situ vitrification (ISV) is a method of immobilizing waste in-place. The waste and surrounding contaminated soil are electrically heated until a molten mass is formed. When this molten mass cools, the result is a monolithic mass of man-made obsidian. This mass of glass-like material has been shown to effectively immobilize inorganic wastes, while driving off VOCs during the heating process. Organic compounds may be destroyed by pyrolysis or may require treatment with other gases released during vitrification. ISV is still a developmental technology. Although it has high potential benefits, especially for radioactive and mixed wastes, ISV has an unproven record. ISV heating must drive off all water and water vapor before the melting and subsequent glassification can occur (Built 1987). The groundwater surface at Plant 4 is near the land surface (a few feet in most areas). ISV shall be eliminated from further consideration due to the technical impracticalities and expense imposed by the need to dewater the soil prior to vitrifying.

Cryogenic Barriers: Cryogenic barriers are constructed using freezing liquid circulated in a closed system in pipes laid below the contamination zone. It is considered a temporary treatment and, therefore, not applicable.

Vapor Extraction: Vapor extraction removes VOCs from the vadose zone by creating a vacuum in the soil that draws the VOCs to an extraction well. It is a proven technology that is considered very effective if site conditions are favorable for its use. The only place it would be considered is for TCE in the vadose zone under Building 181.

Chemical Treatment

Soil Mixing: Deep soil mixing can be used to perform in-situ stabilization/solidification of contaminated soil to depths greater than 100 feet. Four large augers, approximately 3 feet in diameter, are arranged in an overlapping pattern. Stabilizing chemicals are added through the hollow center of the auger as the auger moves through the soil. Early experience with the technology suggests that auger techniques may not be applicable in rocky environments. Studies to determine the leaching characteristics of the stabilized waste, and treatability studies to select the proper stabilization chemicals must be performed before this technology can be used. Shallow soil mixing can be accomplished with a backhoe and the appropriate stabilizing chemicals (EPA 1989b). This option is most applicable to inorganic contaminants. The COC in soil is an organic contaminant, therefore, this option shall be dropped.

Immobilization: Soils contaminated with organics or inorganics may be candidates for stabilization or solidification processes, depending on the types and concentrations of contaminants present in the soil. Cement-based and pozzolanic stabilization/solidification are primarily used for inorganic contamination, while thermoplastic stabilization, macroencapsulation, organic polymerization, and organophilic clay-based processes are primarily used for organic contaminants. Because of the non-homogeneity of most contaminated soils and the variability of the stabilization/solidification processes, extensive treatability studies are usually performed prior to selection of a particular process. Prior experience in various industries has shown that very small amounts of certain compounds and chemicals can significantly affect the strength and leach characteristics of the solidified product (EPA 1989b).

This option requires extensive testing prior to use and is similar to soil mixing. This option is potentially applicable for inorganics/metals but may not be effective for organic contaminants, therefore, it shall be eliminated as an option at this point since the soil COC is organic.

Soil Washing: This technology may occur in-situ or above ground. In the above ground process, excavated soil is fed into a soil washing system which uses water, organic solvents, surfactants, or other chemicals to extract contaminants from the soil. In the in-situ process, the washing fluid is sprayed onto or otherwise mixed into the soil. Contaminants are extracted into the fluid, which is pumped from the groundwater below. The washing fluid is then treated for reuse or disposal. This technology may not be suitable for high clay content or high organic content soils. The technology has been demonstrated to remove inorganics, SVOCs, fuels, and selected VOCs and pesticides. Among the factors that limit the applicability of this technology are complex waste mixtures (metals with organics) that make formulating a washing fluid difficult (EPA 1994). This option could be effective at removing BAP from the soil. However, it is being eliminated from further evaluation because additional treatment, such as stabilization, of the residuals would probably be required.

Thermal Treatment

This technology includes options of incineration and low-temperature thermal stripping. Incineration destroys organic contaminants. Low-temperature thermal stripping volatilizes and drives off organic contaminants. The known presence of metals in Landfill No. 4 indicates that thermal treatment for the BAP would be significantly complicated by the creation of high metal content treatment residuals that would require further treatment followed by off-site disposal. Therefore, thermal treatment shall be eliminated as an option.

Biological Treatment

Biodegradation can be either by aerobic or anaerobic means. The microorganisms metabolize organic contaminants and usually produce a benign waste. The heterogeneous nature of a landfill would make this a very difficult option to implement, therefore, it will be eliminated from further consideration.

Removal/Disposal**Excavation**

Excavation can generally be accomplished using conventional construction equipment and techniques. Some modifications would be made to prevent contact with hazardous components that may be present in the soil being excavated. In addition to chemical hazards, explosive hazards may exist due to containers in the old landfills. This option shall be retained for further analysis.

Disposal

Off-site Disposal: Excavated soil and debris must be disposed in a RCRA-permitted landfill if it is considered RCRA hazardous waste. The RCRA land disposal restrictions prohibit disposal in permitted landfills unless the waste has been treated to specified levels of contamination. The levels of contamination found in most of the soil at Plant 4 are below the concentrations the BDAT can treat to; however, the soil "hot spots" may be contaminated in sufficient concentrations to invoke RCRA LDRs. Therefore, while the LDRs would not affect the majority of the contaminated soil volume, a small volume of "hot spot" soils would require further treatment prior to land disposal. Also, residuals from on-site treatment may have to be landfilled. An off-site landfilling option shall be retained for further evaluation.

On-site Disposal: RCRA landfills can be constructed on-site if the soil has been treated to specified levels of contamination. USAF regulations however prohibit new landfills on Air Force property, therefore, on-site landfilling shall be discarded for any material that is RCRA hazardous waste. Inorganic contaminated soil in Landfill No. 3 and Meandering Road Creek could be disposed at Landfill No. 4, if it was not hazardous waste.

Table 2-6 summarizes the general response actions, technology types, and process options considered for soil and sediment remediation. The table includes a description of the processes and preliminary screening comments about whether the process option is being retained for consideration.

Table 2-6 Technology Types and Process Options for Soil/Sediment

General Response Action	Technology Type	Process Options	Description	Comments
No-Action	None	Not Applicable	No-Action	Required to be retained by NCP
Institutional Controls	Access Restrictions	Access Restrictions	Physical limitations to prevent access to land and groundwater	Not applicable, exposed population is site workers, not general public
		Deed Restrictions	Limiting land and groundwater use by subsequent owners	Not applicable, land owner not likely to change
		Grout Curtains	Tubes of grout surround the contaminated area	Not applicable, does not control exposure pathways
Containment	Barriers	Slurry Walls	Inject clay slurry in continuous trench around contamination	Not applicable, does not control exposure pathways
		Sheet Piling	Driving interlocking steel walls around contamination	Not applicable, does not control exposure pathways
		Asphalt, clay, concrete, synthetic	Install near-impermeable cover to prevent infiltration to prevent contaminant movement	Potentially applicable
Treatment	Physical	Vitrification	Electrically melt soil in-situ to vaporize contaminants or immobilize them in place	Limited by presence of groundwater near surface
		Cryogenic Barriers	Freezing soil by placing pipes and circulating liquid in closed system	Temporary, not proven
		Vapor Extraction	Extracting VOCs in the soil by creating a vacuum	Potentially applicable only to VOC contamination
	Chemical	Soil Mixing	Using augers to mix in stabilizing chemicals	Not applicable for organic contaminants
		Soil Washing	Removing contaminants by adding solvents, surfactants to soil	Not applicable for BAP
		Immobilization	Using cement grout to immobilize contaminated soil	Questionable for organics, requires extensive testing

Table 2-6 (continued) Technology Types and Process Options for Soil/Sediment

General Response Action	Technology Type	Process Options	Description	Comments
Treatment	Thermal	Incineration	Destroys organic contaminants	Presence of metals excessively complicates residuals disposition
		Thermal Stripping	Drives off organic contaminants	Presence of metals excessively complicates residuals disposition
	Biological	Aerobic	Microorganisms metabolize organic contaminants	Not applicable, difficult to implement in heterogeneous sites, such as landfills
		Anaerobic	Microorganisms metabolize organic contaminants	Not applicable, difficult to implement in heterogeneous sites, such as landfills
Removal/Disposal	Excavation	Excavation	Removing contaminated soil from area	Potentially applicable for both organic and inorganic contamination.
	Disposal	On-site Disposal	Creating RCRA landfill and placing contaminated soil in the landfill or placing non-RCRA soil and sediment at existing landfill.	New RCRA landfill not allowed by Air Force regulations, not applicable. Disposal of non-RCRA soil at existing site may be applicable.
		Off-site Disposal	Sending waste to RCRA approved landfill, if it meets BDAT regulations	Potentially applicable

2.7 Process Option Evaluation

Once the process options have passed preliminary screening, they must be evaluated for effectiveness, implementability, and cost (EPA 1988a). Effectiveness focuses on the option's method to treat the estimated volume of soil and groundwater and its ability to meet the RAO, potential human health and environmental impacts during construction and implementation, and how reliable the option is in treating the contaminants. Implementability refers to the technical and administrative concerns as well as availability of resources. Cost concerns at this point are a relative measure of initial and operating and maintenance (O&M) costs, based on engineering judgment.

Per EPA guidance, only one process option per each technology type will be selected. This will be considered the representative technology and, thus, will simplify the subsequent phases of the FS. The final selection will be made during the final design process.

2.7.1 Groundwater Evaluation

2.7.1.1 Effectiveness

No-Action

No-action relies on natural conditions to degrade or dilute constituents. This may not achieve the RAOs.

Institutional Controls

Monitoring: Monitoring would give valuable information for plume movement, remediation effectiveness, and general groundwater information. It is applicable for all groundwater areas.

Deed Restrictions: Deed restrictions would give any future landowners, if other than the U.S. government, knowledge of contamination that remains on-site. Deed restrictions are applicable to all groundwater areas on Air Force Plant 4 or CAFB. It is not applicable to off-site contamination.

New Water Supply Wells: Drilling new water supply wells would provide a safe, potable water supply for the potentially affected community of White Settlement. It is applicable for the Paluxy dissolved plume.

Containment

Slurry Wall: A slurry wall would prevent further migration of dissolved and possibly DNAPL from continuing to contaminate the Paluxy aquifer. This is applicable only to the Upper Zone groundwater.

Collection/Treatment/Disposal

Vertical Wells: Using vertical wells to remove dissolved contaminants is effective in controlling plume movement.

Surfactants: Surfactants would be effective in the removal of DNAPL by altering its physical properties to promote improved miscibility with water, thus increasing removal quantities.

Air Stripping: Air stripping has been shown to be effective in removing dissolved VOCs.

Carbon Adsorption: Carbon is effective in removing organic compounds. The system must be closely monitored and a back up unit installed because eventually the carbon would have reached its maximum and breakthrough would occur. The spent carbon would either be regenerated or disposed as a hazardous waste. This, of course, would present an additional liability issue. It is not suitable for long term remediation and will be dropped.

Oil/Water Separation: A separator would remove emulsified, floating, and sinking constituents. It would not affect dissolved concentrations. The dissolved fraction must be remediated using another technology.

UV/Oxidation: This treatment has been used in the waste water industry to treat water. It effectively destroys organic compounds.

Discharge to Receiving Waters: This is a very effective option.

Discharge to a POTW: For short-term, discharge to a POTW is effective.

2.7.1.2 Implementability

No-Action

No-action is easy to implement as no work is anticipated.

Institutional Controls

Monitoring: Monitoring would be a part of any remediation plan as one measure of its efficacy and general aquifer parameters.

Deed restrictions: Implementing deed restrictions would be easy to implement for U.S. government owned land, but is not being considered for land not owned by the U.S. government.

New Water Supply Wells: Providing a new water source such as drilling production wells down to the lower aquifer, the Travis Peak/Twin Mountain aquifer, would be easy to implement.

Containment

Slurry Wall: A slurry wall would be moderate in its complexity to construct, given the quantity of underground utilities, depth to confining layer, length of the plume to be cut off, and rising groundwater elevations.

Collection/Treatment/Disposal

Vertical wells: Vertical wells to extract groundwater and NAPL is simple in application but requires specific and detailed site information to be implemented usefully. Well placement, construction, and pumping rates pose the greatest areas of concern. These factors and others would drive the design for the remediation system. With this information, the system can be installed with moderate ease.

Surfactants: Surfactant flooding would be moderate in its implementability.

Air Stripping: Air stripping would be moderate to install and operate due to the volume of water, contaminant concentration, and strata heterogeneity.

Carbon Adsorption: Carbon adsorption is a well documented technology with wide spread use. It is easy to implement though the contaminant volume and therefore, change out periods, increase the O&M costs. It is not as efficient as air stripping for the volume considered.

Oil/water Separation: Oil/water separation would be applied prior to dissolved treatment as part of a total fluids pumping system. The system is easy to install, once the piping is in place. The separated product would be pumped or drained into a holding tank then re-used as a general solvent, sold to a solvent reclamation firm, or disposed as a waste. If the product is disposed as a waste, it probably would meet the definition of a hazardous waste.

UV/Oxidation: UV/oxidation is moderate in its difficulty to be implemented. The flow rate through a particular UV oxidation unit is limited by the contact time required to destroy the contaminant to specified levels. Higher flow rates are attained by adding additional treatment units.

Discharge to Receiving Waters: Discharging treated water to receiving waters is an accepted method of discharging. It presents no significant implementability issues but must meet discharge concentration limits.

Discharge to a POTW: Discharge to a POTW would be easy to implement, given concurrence from the POTW.

2.7.1.3 Cost

No-Action

Since no action entails active remediation, costs are minimal and limited to monitoring costs.

Institutional Controls

Monitoring: Monitoring would involve a moderate cost as it would be a part of almost all remediation alternatives. It would be an on-going activity for the life of the project and after, until all requirements have been met for project closure.

Deed Restrictions: The costs of deed restrictions would involve essentially no capital or O&M costs, only very minimal for incorporating a deed restriction if the land is ever sold.

New Water Supply Wells: Drilling production wells to the lower aquifer for an alternative, potable water supply would be moderate in cost to implement. O&M is expected to be moderate as a result of testing costs.

Containment

Slurry Wall: A slurry wall is expected to have a moderate capital cost and no O&M cost.

Collection/Treatment/Disposal

Vertical Wells: Due to the amount of preparation, testing, and equipment cost, the collection of groundwater through vertical wells would have a moderate capital cost. Once the system is in place, annual costs afterwards are expected to be low, as equipment maintenance should be limited.

Surfactants: The cost of surfactants is thought to be moderate but must be considered as an element of an entire treatment strategy, which overall is expensive.

Air Stripping: Air stripping would have a moderate initial cost for equipment and construction. O&M is expected to also be moderate as the system must be shut down periodically to be maintained.

Carbon Adsorption: Costs for carbon adsorption are exclusively driven by influent and effluent concentrations. Units are expected to be changed on a regular basis and the cost involved would be driven by the concentrations. Costs are expected to be moderate.

Oil/Water Separation: Oil/water separation would have a low capital cost and little O&M.

UV/Oxidation: UV/oxidation would have a high capital cost from construction and equipment costs. O&M costs are expected to be low.

Discharge to Receiving Waters: Discharging to receiving waters would have a moderate capital cost due to construction but a low O&M as maintenance is limited.

Discharge to a POTW: Discharging to a POTW would have a low capital cost but a moderate O&M costs, depending upon the length of time the discharge was sent to the POTW.

Table 2-7 summarizes the effectiveness of the options for groundwater treatment.

Table 2-7 Evaluation of Process Options for Groundwater Remediation

General Response Action	Technology Type	Process Options	Effectiveness	Implementability	Cost
No-Action	None	None	Relies on natural degradation	Easy to implement	Minimal Cost
Institutional Controls	Monitoring	Monitoring	Effective in determining plume movement and remediation effectiveness	Easy to implement	Minimal Cost
	Deed Restrictions	Deed Restrictions	Effective at informing future landowners of contamination, not considered for off-site contamination	Easy to implement	Minimal Cost
	New Water Supply Wells	Development of New Wells for White Settlement	Would provide safe, potable water source	Easy to implement	Moderate cost, moderate O&M
Containment	Physical Containment: Barriers	Slurry Walls	Cuts off further migration into Paluxy	Easy to implement	Moderate cost, no O&M
Collection/Treatment/Disposal	Groundwater extraction	Vertical wells	Would remove contaminated groundwater	Moderate to implement	Moderate capital, low O&M
	Enhanced Removal	Surfactants	Targets source areas	Moderate to implement	High capital, low O&M
	Physical Treatment	Air Stripping	Removes volatile organics from groundwater	Moderate to implement	Moderate capital, low O&M
		Carbon Adsorption	Removes organic compounds, but not efficient, not considered	Easy to implement	Moderate capital, moderate O&M
		Oil/Water Separation	Separating emulsified, floating, or sinking oils, from water	Easy to implement	Low capital, low O&M

Table 2-7 (continued) Evaluation of Process Options for Groundwater Remediation

General Response Action	Technology Type	Process Options	Effectiveness	Implementability	Cost
Collection/Treatment/Disposal	Chemical Treatment	UV/Oxidation	Effective in destroying organic compounds	Moderate to implement	High capital, low O&M
	On-site discharge	Discharge to receiving waters	Would remove contaminated groundwater	Easy to implement	Capital costs dependent on length of pipe required, low O&M
	Off-site discharge	POTW	Effective for short term	Easy to implement	Low capital, low O&M

2.7.2 Soil Evaluation

2.7.2.1 Effectiveness

No Action

No action relies on natural conditions to degrade or dilute constituents. It will work where contamination causes risk, but would take years to be effective. However, for BAP in Landfill No. 4, the risks are barely above threshold values but below the risk value where remediation is usually required. Therefore, no action would result in minimal human exposure. No action would not be effective at reducing the potential ecological risk.

Containment

The containment option retained for consideration is capping. Capping the areas of soil contamination targeted by the PRGs can effectively break the exposure pathways to contaminated soil that were developed and evaluated in the BRA. Capping is being considered for soils and sediments that would first be excavated because they exceed ecological risk threshold values.

Treatment

The treatment options retained at this stage are vapor extraction, in-situ soil mixing, soil washing, and immobilization. Vapor extraction is very effective, but only for VOC contamination. In-situ soil mixing is coupled with immobilization to stabilize contamination in place. The BAP may present problems since the presence of organics generally makes the stabilization chemistry more difficult, but still feasible. Treatment of the soils and sediments that exceed ecological risk involves only inorganics. Stabilization is a proven technology for treating inorganics. Soil washing can be effective for both organic and inorganic contaminants.

Removal/Disposal

Excavation and off-site disposal are being retained because they would meet RAOs if the excavated soil did not require additional treatment. These options must be coupled with a treatment option, such as stabilization, if the excavated soil or sediment exceeds RCRA Land Disposal Restrictions. Excavation would present exposure problems as material is removed and placed into containers for further remediation. On-site disposal is being considered only for inorganic contamination at Landfill No. 3 and Meandering Road Creek and only if the soil and sediment is not RCRA hazardous waste. Off-site disposal would only be possible if the wastes meet RCRA guidelines. These options should satisfy the RAOs for BAP and inorganic contamination.

2.7.2.2 Implementability

No-Action

The no-action option would be easy to implement as no work is anticipated.

Containment

Capping would be an easy option to implement, although the effort may impact day-to-day operations and, therefore, requires coordination with Plant 4 management.

Removal/Disposal

Both excavation of all areas, on-site disposal, and off-site disposal technologies would be relatively easy to implement. Removal may require an equipment operator with special training but this is not expected to cause problems. Equipment required would be standard earth moving equipment, which is readily available.

On-site disposal of inorganics is dependent on the material not being a RCRA hazardous waste. Off-site disposal would be easy to implement but centers on being able to satisfy RCRA landfill requirements which could be difficult. Most commercial hazardous waste landfills would provide the necessary BDAT services as part of the contract.

2.7.2.3 Cost

No action would have minimal cost, if any, associated with it. The only cost that may be associated with no action is monitoring. Institutional controls, like access restrictions, would have a low cost as little capital would have to be invested to limit access by employees to restricted areas. Containment options would have low capital costs and low O&M costs. Removal and disposal would have high capital but no associated O&M costs.

Table 2-8 presents a summary of the effectiveness, implementability, and cost of these process options for soil.

2.7.3 Evaluation Summary

2.7.3.1 Groundwater

The no-action alternative would be retained for comparison. Monitoring, deed restrictions, and drilling to a lower aquifer will remain as part of the institutional controls. The slurry wall will be retained in the event a physical barrier is needed to prevent migration of dissolved contamination into the Window Area. Vertical wells will be the choice for extraction/collection of groundwater. Discharge will be represented by emptying to a POTW and to surface water.

Treatment is more complex as different phases of the contaminants are targeted by various technologies. For the dissolved phase, physical and chemical treatments have been selected as viable: air stripping will be the physical treatment and UV/oxidation will be the chemical treatment. Enhancement of DNAPL extraction may be done with surfactants. Oil/water separation would be used for removal of DNAPL from the influent as a first step in the treatment process.

Table 2-9 summarizes the technology types and process options that passed the initial FS effectiveness, implementability, and cost evaluation.

Table 2-8. Evaluation of Process Options for Soil Remediation

General Response Action	Technology Type	Process Options	Effectiveness	Implementability	Cost
No-Action	None	Not Applicable	Relies on natural degradation	Easy to implement	None
Containment	Capping	Asphalt, Clay, Concrete, Synthetic	Would limit human contact and should achieve RAOs	Moderately easy to implement	Low capital, Low O&M
Removal/Disposal	Excavation	Excavation	Not a remediation by itself, must be coupled with other technologies to achieve RAOs	Easy to implement	Moderate capital, No O&M
	Disposal	On-Site Disposal	Effective only if soil/sediment is not hazardous waste	Easy to implement	Moderate capital, Low O&M
		Off-Site Disposal	Would achieve RAOs, but must meet BDAT regulations	Easy to implement	High capital, No O&M

Table 2-9 Final Groundwater Process Options

General Response Action	Technology Type	Applicability	Process Options
No-Action	Monitoring	All areas	Monitoring
Institutional Controls	Monitoring	All areas	Monitoring
	Alternative Water Supply	Paluxy	Drilling to lower aquifer
Containment	Physical Barrier	Upper Zone dissolved and DNAPL areas	Slurry wall
Collection/Treatment/ Disposal	Extraction	Paluxy and Upper Zone dissolved areas	Vertical wells
	Enhanced DNAPL Recovery	Upper zone DNAPL areas	Surfactants
	Physical Treatment	Paluxy and Upper Zone dissolved areas	Air Stripping
		Upper Zone extracted DNAPL	Oil/Water Separation
	Chemical Treatment	Paluxy and Upper Zone dissolved areas	UV/Oxidation
	Discharge	Paluxy and Upper Zone dissolved areas	Discharge to receiving waters
		Paluxy and Upper Zone dissolved areas	Discharge to a POTW

2.7.3.2 Soil

The no-action alternative will be retained for comparison. Containment will retain capping with asphalt, concrete, or compacted clean soil. On-site disposal is applicable when combined with containment, if the soil/sediment is prohibited by RCRA Land Disposal Restrictions. Removal/disposal retains excavation and off-site disposal as alternatives.

Table 2-10 summarizes the technology types and process options for soil that passed the initial FS effectiveness, implementability, and cost evaluation.

Table 2-10 Final Soil Process Options

General Response Action	Technology Type	Process Options
No-Action	None	None
Containment	Capping	Asphalt, Concrete, Soil
Treatment	Physical Treatment	Soil vapor extraction
Removal/Disposal	Excavation	Excavation
	Disposal	On-site Disposal
		Off-site Disposal

3.0 Development of Alternatives

Process options that passed the initial screening were used to develop alternatives for contaminated groundwater and soil/sediment areas that exceed risk threshold values.

3.1 Groundwater Alternatives

Remedial alternatives for groundwater have been divided into two areas, the Paluxy aquifer and the Upper Zone flow system in the area of the East Parking Lot Plume. Treatment alternatives for the extracted groundwater are evaluated separately because they apply to alternatives for both the Paluxy aquifer and the East Parking Lot Plume. However, unique aspects of a particular groundwater area, such as contaminant concentrations, different contaminants to be treated, or special processes needed to treat groundwater that contains surfactants will be considered in the treatment alternatives.

3.1.1 Paluxy Aquifer Alternatives

The RAO for the Paluxy aquifer is to prevent human exposure from ingestion, inhalation during showering, and dermal exposure from showering to TCE concentrations exceeding $3.0 \mu\text{g/L}$ and to DCE concentrations exceeding $70 \mu\text{g/L}$ for *cis*-1,2-DCE and $100 \mu\text{g/L}$ for *trans*-1,2-DCE. It should be noted that DCE is a degradation product of TCE and is very similar in treatment response.

Alternative 1 - No-action

This alternative assumes that no additional activities would be done to remediate the VOC contaminants in the Paluxy aquifer. The alternative does include monitoring to track the movement and contaminant levels in the aquifer. Monitoring would involve quarterly sampling from 5 wells in and around the Paluxy West Plume and 10 wells in the Paluxy Upper Sand groundwater. Monitoring would be done as long as contamination existed in the Paluxy aquifer and Paluxy groundwater. The no-action alternative is required under CERCLA as a baseline alternative with which to compare other alternatives.

Alternative 2 - Institutional Controls

Preliminary groundwater modelling was performed to determine the impact of TCE on commercial, potable wells in the town of White Settlement. Estimates from the RI determined that TCE would impact the wells in 60 years. To maintain the integrity of the water supply to White Settlement, a source of water that has not been contaminated could be used. Specifically, production wells would be drilled into the aquifer below the Paluxy, the Travis Peak/Twin Mountain aquifer. This aquifer is currently being used by the cities of Fort Worth and White Settlement and has proven production rates and water quality. It is estimated that the affected wells could be re-drilled into the lower aquifer on a one-to-one basis. The new wells would be able to sustain the average production of 50 to 60 gallons per minute. The wells would be an average of 500 to 550 feet deep. This alternative includes monitoring the plume to track its movement and concentration levels but does not include any extraction or treatment of contaminated groundwater. Monitoring would be the same as for the no-action alternative.

Alternative 3 - Dissolved Plume Pump and Treat

This alternative uses treatment and containment technologies. It contains plume movement by extracting groundwater from the leading edge of the plume and removes contaminant mass by extracting groundwater from within the plume and then treats the extracted groundwater. Remediation would continue until cleanup levels are reached.

Remediation and containment of two plumes are included in this alternative. The West Plume is in the upper and middle portions of the Paluxy aquifer located under Landfill No. 3. The Upper Sand plume is located under the Window Area of the East Parking Lot. Also, low levels of contaminants have been found in the upper portion of the Paluxy under the East Parking Lot in well P-8UN.

This alternative also includes monitoring of the Paluxy West Plume and Paluxy Upper Sand groundwater during remediation and after cleanup levels have been reached. The initial plan for monitoring of the Paluxy West Plume would be to do quarterly sampling from 5 wells during remediation and for 2 years after cleanup levels in the Paluxy aquifer are reached. Semi-annual sampling would then continue for 3 more years to ensure cleanup levels are maintained. Quarterly sampling of the Paluxy Upper Sand groundwater would continue during remediation of the East Parking Lot Plume and for 2 more years after remediation was complete. Semi-annual sampling would then continue for 3 more years. Ten wells would be sampled in the Paluxy Upper Sand groundwater.

The strategy to contain the contamination in the Upper Sand portion of the Paluxy Formation would include plume definition in the Upper Sand and then extraction of groundwater, where it is possible. Plume definition would require samples collected from existing wells ending in U, UN, and US and new wells, EX-1, EX-2, and EX-3, to be drilled east P-14US (Figure 3-1).

Well EX-1 would be drilled near the center of the Upper Sand plume to target the area between wells P-8US, P-9US, and P-15US. Monitoring wells in the Upper Sand would be converted into extraction wells, where practical.

The following assumptions have been made for the Upper Sand portion of the Paluxy Formation.

- The three wells discussed above (EX-1, EX-2, and EX-3) would be drilled. EX-1 and EX-2 would have a saturated thickness of 15 feet while EX-3 would be 5 feet. Contaminant levels would be 1,000 µg/L and 100 µg/L, respectively.
- Wells P-8US, P-9US, P-14US, P-15US, P-16US would be pumped at 19 gpm, EX-3 at one gpm.
- Plume definition would include additional monitoring wells in the area of well P-19US and downgradient from P-19US.
- TCE concentrations from Paluxy Upper Sand wells sampled in 1992 would not vary from results of the proposed round of sampling by more than 20 percent.
- The three new wells (EX-1, EX-2, and EX-3) would be drilled 75 feet deep, double cased, with 10 feet of screen.

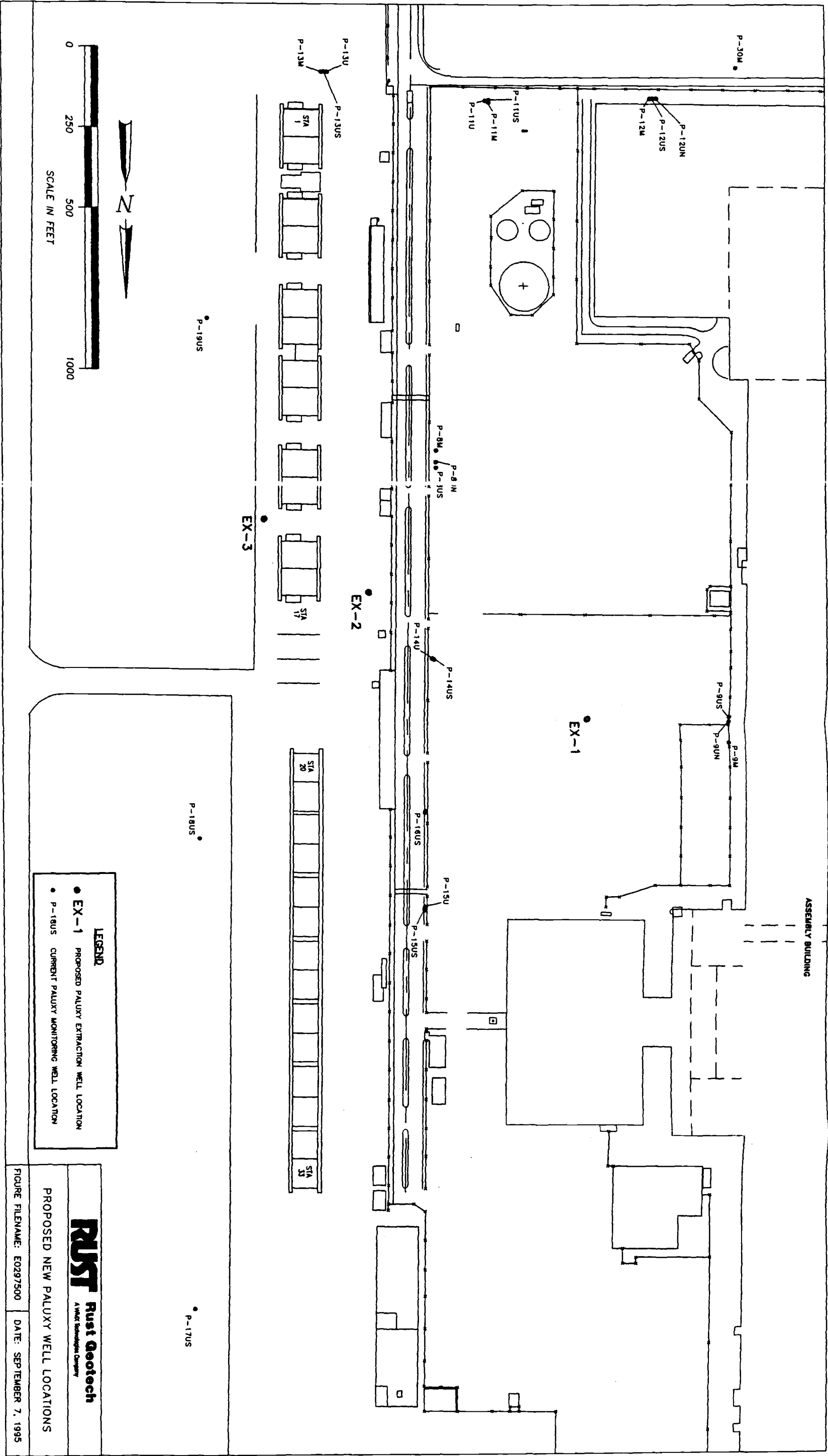


Figure 3-1. Potential Paluxy Upper Sand Extraction Well Locations.

- No DNAPL would be encountered.
- TCE contaminated groundwater volume is computed from 1992 sampling as shown on Figures II-19a, II-19b, II-19c, and II-19d from the RI Report. This gives an average TCE concentration of 700 $\mu\text{g/L}$ over a revised contaminated volume of 3.8×10^7 gallons. Porosity is assumed to be 25 percent.
- A pump/slug test would verify these pumping rates as correct.
- Costs may be impacted once the results of groundwater modelling have been completed. For example, if the model shows that conductivities are lower than assumed, the time to remediation could be longer, resulting in higher than estimated costs.

The following assumptions have been made for the Paluxy aquifer.

- Sampling would be performed and would verify the presence of TCE within 20 percent of the 1991 sampling event.
- P-22U and P-22M in the Paluxy West Plume would be plugged.
- The Paluxy West Plume has an estimated contaminated volume of 5.4×10^6 gallons.
- Pumping rates for the Paluxy West plume are estimated at 45 gpm. The wells would be drilled approximately 75 feet deep, double cased, with 10 feet of screen.
- P-8UN may be used as an extraction well if levels exceed the PRG.
- Plume definition under the East Parking Lot would require an additional monitoring well downgradient from well P-19US.
- Ten pore volumes would be required to remove contamination from the Paluxy West plume (5.4×10^7 gallons).
- Costs may be impacted once the results of groundwater modelling has been completed. For example, if the model shows that conductivities are higher than assumed, the time to remediation could be shorter, resulting in lower costs.

The estimated contaminated volume was calculated using CPS-PC, a 3-dimensional contouring package, AutoCAD version 12, and aquifer data collected during the RI. The program uses a least squares method to calculate areas and volumes. This assumes that the TCE concentration is vertically uniform. It was assumed that a total of 10 pore volumes would be necessary to flush the sorbed contaminants from the aquifer matrix (Mackay 1989). The information listed in Appendix C includes the above mentioned data, a summary of the methodology, and the final volume calculations.

The treated water is expected to be discharged to Meandering Road Creek.

The selected treatment alternative would be combined with this alternative for treatment of the extracted groundwater. The selected treatment system would be located to limit piping distance, quantity, and size of remediation systems.

3.1.2 Upper Zone - East Parking Lot Plume

The RAOs for the Upper Zone flow system in the area of the East Parking Lot Plume are to prevent TCE concentrations in the Window Area from exceeding 250 $\mu\text{g/L}$, remove DNAPL in the East Parking Lot Plume, and prevent groundwater with contamination above MCLs from leaving Plant 4 or CAFB. Removal of DNAPL would be demonstrated by dissolved concentrations of TCE less than 10,000 $\mu\text{g/L}$. Meeting the RAO to prevent contamination of the Paluxy aquifer requires that TCE concentrations be reduced to 250 $\mu\text{g/L}$ within 250 feet around well W-149.

Contamination in the East Parking Lot Plume has moved onto CAFB and all alternatives assume that future land use on CAFB would be industrial, the same as Air Force Plant 4. Also, monitoring for all alternatives includes the North Plume, the West Plume, Meandering Road Creek, Lake Worth, surface water on CAFB, and the East Parking Lot Plume.

The monitoring plan for all the alternatives is similar. Monitoring the area with the highest contaminant levels in the East Parking Lot plume would involve 10 wells sampled quarterly for as long as contaminant levels remained above RAOs. Monitoring the North plume, including Lake Worth, will be done semi-annually and involve 5 sampling points (wells or surface water samples). Monitoring the West plume, including Meandering Road Creek, also will be done semi-annually and involve 5 sampling points (wells or surface water samples). Monitoring the perimeter of the East Parking Lot plume, including surface waters on CAFB, will be semi-annually and involve 20 sampling points (wells or surface water samples).

Alternative 1 - No-action

This alternative assumes that no additional activities would occur to impede or remediate the DNAPL areas or dissolved TCE. The alternative does include monitoring to track the movement of the plume and concentration of contaminants in the plume. The no-action alternative is required under CERCLA as a baseline alternative with which to compare other candidate alternatives.

Alternative 2 - Source Removal/ Window Area Dissolved Plume Remediation/ Containment

This alternative makes use of treatment and containment for DNAPL removal and dissolved plume remediation in the Window Area. The remediation strategy is to first remove DNAPL from the area under Building 181 and the Window Area. Once DNAPL has been removed, the Window Area may need to be physically separated from upgradient areas of high dissolved TCE concentrations so as to limit the amount of groundwater requiring remediation to low dissolved concentrations and reduce the time of remediation. Separation of the Window Area may not be required if upgradient dissolved concentrations do not affect the Window Area. Determination of whether separation is required would be determined once the DNAPL has been removed.

Separation, if required, could be accomplished with a slurry wall, interceptor trench, or horizontal well. The technology to use for separation will be determined when the decision is made that separation is required. A slurry wall would run northeast to southwest, be placed as close as possible

to the upgradient end of the Window Area, and be tied into competent Walnut Formation. A slurry wall would be used to direct contaminated groundwater away from the Window Area. It would not be used to stop groundwater flow and would probably require a drain directly upgradient to assist groundwater flow movement. An interceptor trench or horizontal well would be used to intercept the flow and would require groundwater extraction to be effective. Figure 3-2 shows a possible location for the slurry wall.

DNAPL removal would be expedited by injecting clean water to help increase dissolution. Extraction wells would be placed immediately downgradient of DNAPL areas to capture the increased flow. DNAPL removal upgradient of the Window Area would be concentrated in areas with TCE concentrations greater than 10,000 $\mu\text{g/L}$. DNAPL removal would be by ambient dissolution into groundwater followed by traditional well extraction techniques. The indicators for DNAPL removal developed in Section 2.3.1.2 will be used as the basis for when to stop remediation. Extracted groundwater would be treated by the method of the selected treatment alternative.

This alternative also makes use of institutional controls to ensure industrial future land use on Air Force Plant 4 and CAFB. The alternative also includes monitoring all areas of contamination in the Upper Zone flow system or areas that could be affected by contamination in the Upper Zone flow system. This includes the North Plume, West Plume, East Parking Lot Plume, surface waters on CAFB, Meandering Road Creek, and Lake Worth. The initial plan for monitoring is that quarterly monitoring would continue for 2 years after remediation stops and then semi-annual monitoring would continue for 3 more years. Monitoring would include sampling 45 wells.

Monitoring would track any movement of the East Parking Lot Plume so that remedial measures can be taken to contain the plume before it moves off Air Force Plant 4 or CAFB property. Remedial measures would be similar to the voluntary action taken at Landfill No. 3. The voluntary action at Landfill No. 3 uses an interceptor trench and an interceptor well system.

Alternative 3 - Enhanced Source Removal/ Window Area Dissolved Plume Remediation/ Containment

This alternative is the same as Alternative 2 except that removal of DNAPL areas would be enhanced by the use of surfactants. Surfactants are an innovative source removal technology. Of all the enhanced removal techniques (surfactants, cosolvents, alkali, steam or hot water addition) surfactants was judged to be the most applicable for this site. Surfactants increase the solubility of DNAPL allowing greater recovery rates through extraction.

Surfactants would be used to remove DNAPL under Building 181 and in the Window Area. Because the flow system is heterogeneous, removing DNAPL from low permeability areas would be difficult. However, it is unlikely that significant amounts of DNAPL would have moved into low permeability areas because the capillary forces inhibit movement of DNAPL into these areas. However, if DNAPL has moved into these areas, techniques have been used in the oil industry to introduce surfactants into low permeability areas (Lake 1989).

Air stripping would be used as the treatment method to allow for reuse of the surfactants. The residual dissolved phase plume would be removed by conventional pump and treat, similar to Alternative 2. Also, this alternative would use the same institutional controls, potential separation of the Window Area with a slurry wall, indicators of DNAPL removal, and monitoring as Alternative 2.

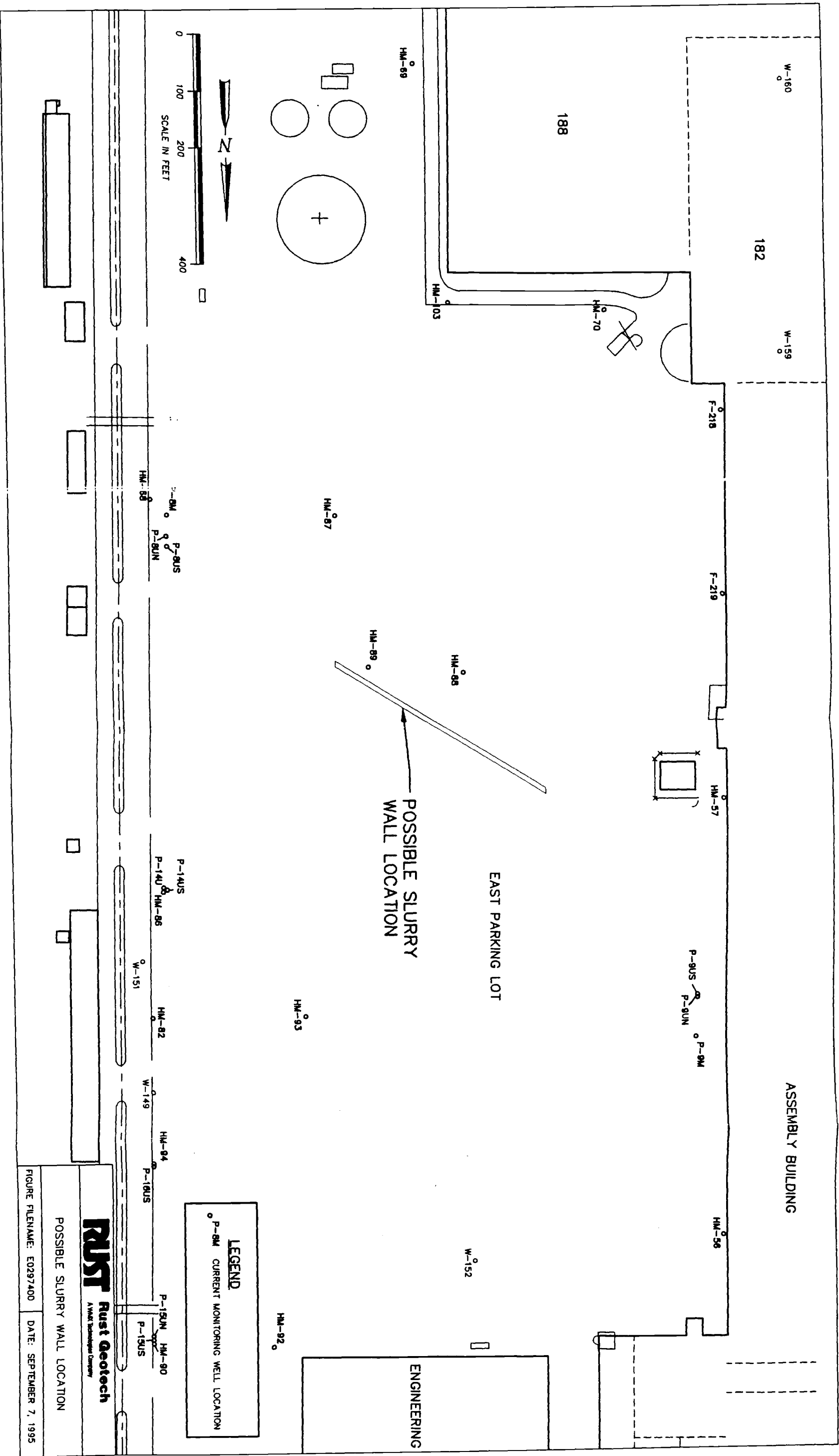


Figure 3-2. Possible Slurry Wall Location in East Parking Lot.

3.1.3 Treatment Alternatives

The treatment alternatives that represent the preferred physical, chemical, and biological treatments are presented below. The selected treatment alternative would be combined with the selected remedial alternative for the Paluxy aquifer and the East Parking Lot Plume.

Treatment Alternative 1 - Air Stripping

This alternative uses air stripping to treat the VOCs (primarily TCE and DCE) in the extracted groundwater. The air stripping system for this alternative would be very similar to the system currently operating in the East Parking Lot. The system would have an influent tank to handle variations in the pumping volumes, an air stripper tray system or tower, and possibly carbon adsorption as a polishing step. The system for the East Parking Lot Plume would require an oil/water separator because of the chance of extracting DNAPL. The system for the Paluxy aquifer would not require an oil/water separator because DNAPL is not suspected. Also, the system for the East Parking Lot Plume that would be combined with surfactant enhanced extraction would require lower flow-through rates that requires more air stripping towers or trays.

Air stripping is a process that transfers dissolved volatile compounds to the vapor phase through the use of high energy air and physical dispersion of the water stream or merely high energy air. Two basic configurations are available, the tower stripper or the tray stripper.

The tower stripper uses a spray nozzle to disperse the water stream over a calculated height of air stripper packing. This packing consists of specially engineered shapes of plastic. It serves to further disperse the water stream to present the largest possible surface area for contact. As the water trickles down through the packing, air is forced upward from below through the blower inlet. The dissolved contamination can then be volatilized because the energy from the air would be concentrated on volatilization instead of water dispersion.

The other major type of stripper, the tray stripper, uses a vertical stack of screens to disperse the water stream. High energy air is added from below and moves upward through the screens and the thin water stream to volatilize the contaminants. This configuration tends to be limited in the water flow rate it can remediate due to the use of screens versus packing to disperse the water. The screens present a lower surface area and, therefore, cannot operate at high flow rates (greater than 50 gpm) because flooding in the trays would occur. Other factors governing the operation of the system is the biological and inorganic concentrations such as iron, carbonate, and manganese in the water stream. As the system continues operation, the increased quantity of scaling and growth would cause continuously decreasing volatilization rates to the point where the regulated discharge limits may not be met. This problem can be prevented by using a pro-active cleaning program such as scheduling equipment maintenance or injecting additives into the water to inhibit growth and scaling or a combination of the two. This is a well proven technology, in use at thousands of sites around the continent and as evidenced by the number of air stripping equipment manufacturers.

Treatment Alternative 2 - Ultraviolet Oxidation

This alternative uses UV light and oxidation, in the form of ozone or hydrogen peroxide, to treat the groundwater. The chemical process involves the generation of hydroxyl radicals through photolysis of hydrogen peroxide or ozone which cause the organic contaminant to undergo a series of oxidation reactions leading to the complete mineralization of the contaminant. The highly reactive hydroxyl radicals are generated from both the high energy UV and the addition of highly reactive ozone or hydrogen peroxide to the contaminated groundwater stream.

Some "stripping" or volatilization of the constituent would occur due to the air flow rate of ozone when added to the water stream. This would vary greatly with the type of contaminant, its concentration, and the air to water ratio. Due to this variability, it is not possible to derive estimated percents of removal due to stripping; however, it is expected to be small in comparison to oxidation. Various parameters affect the efficiency of this treatment method. It can be affected by high alkalinity and turbidity; high values may render the process ineffective. Also, sources of naturally occurring carbon would compete for the radicals, thus lowering the efficiency and requiring an increase in the free radical production. The natural pH of the water would also affect efficiency and may be required to be treated to provide the optimum range for oxidation. This option of treatment is not applicable for the East Parking Lot Plume that uses surfactant enhanced extraction.

If this alternative is used for treatment of extracted groundwater from the East Parking Lot Plume, an oil/water separator would be added for removal of DNAPL. The separator uses the density and immiscibility of DNAPLs as well as a coalescing filter to separate the water stream from the DNAPL.

3.2 Soil Alternatives

There are four areas at Plant 4 with soil contamination that warrant development of remedial alternatives, based on the results of the BRA. The areas are Landfill No. 3, Landfill No. 4, Meandering Road Creek, and Building 181.

3.2.1 Landfill No. 4, Landfill No. 3, and Meandering Road Creek

Landfill No. 4, Landfill No. 3, and Meandering Road Creek are grouped together for remedial alternatives because they have contamination problems that lend themselves to similar remedial alternatives. The alternatives make use of containment, excavation, on-site disposal, off-site disposal, and monitoring.

Monitoring is included in all the alternatives except Alternatives 3a and 3b. Monitoring would be required as long as the waste remains on-site and would involve annual sampling from Lake Worth and Meandering Road Creek.

Alternative 1 - No Action

The no action alternative assumes that additional activities would not occur that would remediate the identified contaminated soil. This alternative is required under CERCLA as a baseline alternative with which to compare other candidate alternatives.

Alternative 2a - Capping (addresses human health risk)

This alternative involves capping areas that contain BAP contamination in the soil (areas that exceed human health risk threshold values). It does not include areas where contamination exceeds ecological risk threshold values, except for the areas on Landfill No. 4. Because contamination that exceeds ecological risk threshold values is within the top five feet of soils at Landfill No. 4, a cap would have the effect of breaking this exposure pathway.

Capping would break the occupational ingestion of soil exposure pathway to achieve the RAO. Although not required to meet the RAO, capping also would decrease surface migration of contaminants by overland flow or runoff and decrease air entrained contaminated particles as well as infiltration contaminant transport. However, this cap would not be designed to the standards of a RCRA cap for a hazardous waste landfill.

Several different types of caps are available. Types of materials used for caps typically include asphalt, concrete, clay, and synthetic material. All four of these materials could be used in caps and would achieve the RAO. Asphalt and concrete caps have the added value of being a "working surface" (i.e. parking lot) due to their inherent material abilities. Synthetic and clay caps can have a shorter life if not maintained. This is especially true of synthetic caps where, if exposed, weather elements and time may eventually degrade the cap to the point where contact can occur. Clay can be subject to physical and chemical attack from certain chemicals.

An effective cover could be constructed of concrete, asphalt, compacted soil, or synthetic material. A clay cap or synthetic cap would allow the area to be covered with top soil to allow for vegetation. If capping is chosen as the preferred alternative, the remedial design process would optimize cap design with respect to the cost and durability. This could result in a cap consisting of a combination of materials. The type of cover chosen for final design would be based on anticipated future uses of the site, regulatory input, and community input. For the conceptual-level purposes of this FS, an asphalt cap over Landfill No. 4 will be the type of cover material assumed.

Alternative 2b - Excavation of Soil and Sediments/ Capping (addresses all human health and ecological risk)

This alternative is the same as Alternative 2a except that in addition to BAP contaminated areas it includes sediments in Meandering Road Creek and Lake Worth that have silver concentrations which exceed ecological risk threshold values and soils in Landfill No. 4 and Landfill No. 3 that exceed ecological risk threshold values. The alternative calls for excavation of sediments in the creek and lake bottom and soils at Landfill No. 3 and then placement of the excavated sediments and soils on Landfill No. 4. Pretreatment of the excavated sediments to reduce moisture content may be required before placement in Landfill No. 4. Moisture reduction of the sediments could be accomplished by mixing them with soils from Landfill No. 4.

This alternative assumes that excavated sediments and soils would pass TCLP tests and, therefore, would not be RCRA hazardous waste. Sediments that fail the TCLP test would require stabilization and then disposal in an off-site hazardous waste landfill.

Alternative 3a - Removal/Disposal (addresses human health risk)

This alternative includes areas that contain BAP contamination in the soil. It does not include areas where soil and sediment contamination exceeds ecological risk threshold values. Areas with contamination that exceed ecological risk threshold values would be left in-place, including the areas at Landfill No. 4.

Removal and disposal of contaminated soil is the least technical approach to achieving the RAOs. The soil would be excavated and placed in suitable containers for disposal at an approved RCRA landfill. TCLP tests would be performed on the soil to determine if it was RCRA hazardous waste. Soil that did not pass the TCLP tests would require solidification before disposal in a hazardous waste landfill. Selection of a landfill would be based on compliance with EPA's off-site policy, the possession of the proper EPA permits, and EPA's approval and acceptance of the waste stream.

Approximately 32,000 cubic yards of contaminated soil in Landfill No. 4 would require excavation and removal. The excavation would take place in the identified area of BAP contamination. Considerable site preparation is necessary under this alternative. The area would require storm water run-on and run-off control. Special considerations are a possibility in the Landfill No. 4 area because of the proximity to Meandering Road Creek which is considered a wetlands.

Alternative 3b - Excavation/Disposal (addresses all human health and ecological risk)

This alternative is the same as Alternative 3a except that in addition to BAP contaminated areas it includes all contaminated areas that exceed ecological risk threshold values. In addition to BAP contaminated soil in Landfill No. 4, contaminated sediments in Meandering Road Creek and Lake Worth and contaminated soils in Landfill No. 4 and Landfill No. 3 would be excavated and removed for off-site disposal. As with the BAP contaminated soil, TCLP testing of the inorganic contaminated sediments and soils would be required to determine whether they are RCRA hazardous waste.

3.2.2 Building 181

TCE is found in the vadose zone beneath Building 181. Pilot tests have been done to test the feasibility of SVE and have shown it to be effective at removing TCE from the vadose zone. Remedial alternatives have been limited to the no action alternative and SVE because EPA has established SVE as the presumptive remedy for VOC contamination in the vadose zone, where it is applicable.

Alternative 1 - No Action

The no action alternative assumes that additional activities would not occur that would remediate the VOC contaminated soil. This alternative is required under CERCLA as a baseline alternative with which to compare other candidate alternatives.

Alternative 2 - Soil Vapor Extraction

An SVE system would be used at Building 181 to remove TCE from the vadose zone. The area of the extraction systems includes the area under Building 181 and Building 182. The system would involve 18 vapor recovery wells, a blower to create a vacuum in the wells and extract the VOCs,

vapor phase carbon adsorption units, and soil gas probes to monitor vacuum extraction performance. The system would continue until cleanup levels have been reached.

SVE works by creating a vacuum in the recovery wells that volatilizes the TCE causing it to be drawn into the wells. The vapor is then conveyed by piping to vapor phase carbon adsorption units where the TCE adheres to the carbon and is later destroyed when the carbon is regenerated. The air that is now free of TCE can be vented to the atmosphere.

The system also includes a vacuum-enhanced groundwater extraction system for treatment of contaminated perch groundwater. Perch groundwater sits on clay layers in the vadose zone, above the Upper Zone groundwater.

Another method of removing the TCE from the air is to destroy the TCE with catalytic oxidation. Carbon adsorption and catalytic oxidation are equally effective at removing TCE from the air. The difference between the two is in cost. Catalytic oxidation involves higher capital costs while carbon adsorption involves higher operating and maintenance costs. If this is the selected alternative, the remedial design should determine which method would be most appropriate for this site.

4.0 Detailed Analysis of Alternatives

4.1 Introduction

This section presents results of the detailed analysis of remedial alternatives that were developed from the technologies and process options that passed screening in the initial phase of the FS. The detailed analysis of alternatives has been conducted in accordance with the National Contingency Plan (NCP). This detailed analysis assesses individual remedial alternatives against the nine CERCLA evaluation criteria and compares the relative performance of each remedial alternative against the criteria. The nine CERCLA evaluation criteria are:

- overall protection of human health and the environment;
- compliance with ARARs;
- long-term effectiveness and permanence;
- reduction of toxicity, mobility, or volume;
- short-term effectiveness;
- implementability;
- cost;
- State acceptance; and
- community acceptance.

Evaluation of the State acceptance criteria will be done after review of the RI/FS and Draft Proposed Plan and included in the Proposed Plan presented to the public. Evaluation of the community acceptance criteria will be done after the public comment period on the Proposed Plan.

4.1.1 Methodology

The detailed analysis phase of the FS includes two components. The first component is an individual detailed analysis for each of the candidate remedial alternatives, which evaluates each remedial alternative using the first seven criteria listed above. The second component is a comparative analysis of alternatives that review the relative overall level of performance among the alternatives.

4.1.2 Detailed Analysis Process

For the detailed analysis of the remedial alternatives developed in the initial phase of the FS, each remedial alternative is evaluated independently using the following evaluation criteria from the NCP:

1. *Overall protection of human health and the environment.* Alternatives shall be assessed to determine whether they can adequately protect human health and the environment, in both the short- and long-term, from unacceptable risks posed by hazardous substances, pollutants, or contaminants present at the site by eliminating, reducing, or controlling exposures to levels established during development of remediation goals. Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

2. *ARARs*. The alternatives shall be assessed to determine whether they attain applicable or relevant and appropriate requirements under federal environmental laws and state environmental or facility citing laws or provide a basis for invoking a waiver.
3. *Long-term effectiveness and permanence*. Alternatives shall be assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative would prove successful. Factors that shall be considered, as appropriate, include:
 - Magnitude of residual risk remaining from untreated waste or treatment residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.
 - Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste. This factor addresses, in particular, the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative, such as a cap, a slurry wall, or a treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.
4. *Reduction of toxicity, mobility, or volume through treatment*. The degree to which alternatives employ recycling or treatment that reduces toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed by the site. Factors that shall be considered, as appropriate, include: (1) the treatment or recycling processes, the alternatives they employ, and the materials they will treat; (2) the amount of hazardous substances, pollutants, or contaminants that will be destroyed or recycled; (3) the degree of expected reduction in toxicity, mobility, or volume of the waste due to treatment or recycling and the specification of which reduction(s) are occurring; (4) the degree to which the treatment is irreversible; (5) the type and quantity of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate such hazardous substances; and (6) the degree to which treatment reduces the inherent hazards posed by principal threats at the site.
5. *Short-term effectiveness*. The short-term impacts of alternatives shall be assessed considering: (1) short-term risks that might be posed to the community during implementation of an alternative; (2) potential impacts on workers during remedial action and effectiveness and reliability of protective measures; (3) potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and (4) time until protection is achieved.
6. *Implementability*. The ease or difficulty of implementing the alternatives shall be assessed by considering the following types of factors as appropriate: (1) technical feasibility, including technical difficulties and unknowns associated with the construction and operation of the technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy; (2) administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions); and (3) availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and

specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and the availability of prospective technologies.

7. *Cost.* The types of costs that shall be assessed include the following: (1) capital costs, including both direct and indirect costs; (2) annual operation and maintenance costs; and (3) net present value of capital and O&M costs.
8. *State acceptance.* Assessment of State concerns on the RI/FS will be addressed, in the Proposed Plan issued for public comment. State concerns that shall be assessed include: (1) the State's position and key concerns related to the preferred alternatives and other alternatives; and (2) State comments on ARARs or the proposed use of waivers.
9. *Community acceptance.* This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about or oppose. This assessment may not be completed until public comments on the Proposed Plan are received.

Overall protection of human health and the environment and compliance with ARARs (unless a specific ARAR is waived) are the *threshold criteria* that each alternative must meet in order to be eligible for selection as the recommended alternative. Long-term effectiveness and permanence, implementability, short-term effectiveness, reduction of toxicity, mobility and volume through treatment, and cost are the *balancing criteria*. The remaining two criteria, state acceptance and community acceptance, are the *modifying criteria*.

4.1.3 Comparative Analysis of Alternatives

The comparative analysis assesses the relative performance among the alternatives against the evaluation criteria. Each alternative is evaluated individually against the threshold criteria and the primary balancing criteria. A comparative analysis is then prepared which gives a positive, neutral, or negative ranking for each alternative relative to the other alternatives. A comparative analysis summary indicates a net ranking for each alternative in order to aid in identifying a recommended alternative.

4.2 Detailed Analysis of Groundwater Alternatives

This section presents the results of the detailed analysis for each remedial alternative. The detailed analysis in this section uses seven of the nine CERCLA criteria, as previously described. The evaluation of alternatives reflects the scope of the remedial action under consideration and the site problems being addressed.

Groundwater alternatives are presented for two systems, the Paluxy aquifer and the East Parking Lot Plume in the Upper Zone flow system. Treatment processes are evaluated separately because they apply to several alternatives. However, treatment costs are included in the cost of the alternatives for the Paluxy aquifer and East Parking Lot Plume, where appropriate.

4.2.1 Paluxy Alternatives

4.2.1.1 Overall Protection of Human Health and the Environment

Overall protection of human health and the environment is based on a comprehensive evaluation of each remedial alternative against the previously described evaluation criteria of long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. Evaluation of overall protectiveness is considered by the NCP to be a threshold criterion, and failure to meet this criterion generally eliminates an alternative from further consideration. Assessment of an alternative's protectiveness integrates the analyses made under the other threshold criterion (i.e. compliance with ARARs) as well as under the primary balancing criteria, especially long-term and short-term effectiveness and permanence.

In order to meet this criterion, alternatives must adequately address the site-specific RAOs and must demonstrate protectiveness:

- Through their ability to eliminate, reduce, or control existing and potential risks associated with transport/exposure pathways.
- By providing engineering controls and/or institutional controls in instances where risks to human health and the environment will remain after completion of remedial actions.
- Through prevention of unacceptable risks and/or environmental contamination during alternative implementation.

Alternative 1 - No Action

The no-action alternative would cause a decrease in concentrations measured across the site over time. What would be occurring is some degradation due to natural decomposition but the majority would be dispersed from the plume as it migrates with the groundwater flow. Preliminary estimates from the RI show that TCE is expected to impact the potable wells in White Settlement. This leads to ingestion of contaminants by the populace, as the wells are commercial and serve that area. This alternative does not adequately provide any control or prevention of exposure risk. It does not attempt to reduce or eliminate the plume which would attempt to control exposure. This has been supported by the BRA, which concluded that contaminants exist which exceed health risk threshold values.

Alternative 2 - Institutional Controls

To ensure that the White Settlement population is not adversely impacted by the presumed contamination of their potable production wells and create an unacceptable health risk, a new water supply must be procured. The second aquifer, below the Upper Zone and Paluxy, the Travis Peak/Twin Mountain aquifer, is currently being used for production purposes by the cities of Fort Worth and White Settlement and has verifiable production rates and water quality.

Alternative 3 - Dissolved Plume Pump and Treat

The groundwater extraction system would first control, then reduce to acceptable levels, dissolved concentrations in the groundwater. The treated water is expected to first be discharged to a POTW then when compliance with NPDES can be demonstrated, discharge would be sent to surface water.

4.2.1.2 Compliance with ARARs

Analysis of ARARs for groundwater complies with Section 121(e) of CERCLA. Although no Federal, state, or local permits are required for on-site activities where remedial action is planned, compliance with the substantive provisions of compliance requirements is necessary.

Alternative 1 - No Action

Failure to perform remedial action at Air Force Plant 4 would result in non-compliance with Federal and state regulatory requirements. Selection of this alternative would result in violation of the SDWA, National Primary and Secondary Drinking Water Standards (40 CFR 141, #143) and the TAC, Title 31, Part IX, Chapter 290 (Texas Drinking Water Standards). Also, because it appears likely that TCE would contaminate White Settlement potable water wells within 60 years, the No Action Alternative is not considered feasible. Selection of the No Action Alternative would also result in not meeting the goals of the National Environmental Policy Act (NEPA) for protection of the environment.

Alternative 2 - Institutional Controls

Providing a safe potable water supply would meet the SDWA and the Texas Drinking Water Standards mentioned above but would not affect the CWA or NEPA as this alternative does not provide environmental remediation options.

Alternative 3 - Dissolved Plume Pump and Treat

Discharge of the treated groundwater could be to a POTW or to receiving surface waters, upon demonstrating compliance with NPDES guidance. The discharge system would comply with regulated permits.

4.2.1.3 Long-Term Effectiveness and Permanence

The primary focus is to address the results of the remedial action in terms of the risk remaining after the RAOs have been met. The effectiveness and reliability of the alternative and the residual risk of untreated waste should be considered.

Alternative 1 - No Action

Because this method does not propose treatment or remediation methods, and sources and exposure routes have been defined, this solution would not be effective in the future, nor is it a permanent solution. Since no-action would be anticipated under this alternative, the risk factors derived by the BRA would be expected in the future. Eventually, however, the risk is expected to diminish due to natural degradation of the plume.

Alternative 2 - Institutional Controls

This alternative would eliminate the health risk due to ingestion for the population of White Settlement. It is a completely reliable and effective method to provide a potable water source. The production wells are expected to be triple cased, one for each flow system, in order to prevent cross-contamination. This alternative, however, does not completely address the residual risk due to non-treatment of the contaminants in the Paluxy aquifer. The plume movement rate in the future would be slower than its present movement because current pumping of the Paluxy aquifer increased groundwater velocities. The cessation of production pumping from the Paluxy would result in lower groundwater velocities.

Alternative 3 - Dissolved Plume Pump and Treat

The extraction system would remove the quantity of contaminated water in the Paluxy. Suitable controls and maintenance would prevent exposure due to equipment failure. If the pump equipment and wells are properly maintained, they would retain their performance specifications. Maintenance should be scheduled to provide optimum system operation without causing severe delays and system shutdown. It is expected that parts would need to be replaced due to wear, but would be included as part of the regular O&M. Controls on the extraction system would affect pump operation to prevent damage to the pump and system failure. If needed, the system can be designed with redundancies in the event of a control failure.

4.2.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Preference is given to alternatives that use treatment to permanently, irreversibly, and significantly reduce toxicity, mobility or volume of the hazardous substance. The amount of material that would be treated, the degree to which it would be treated, and the type and quantity of residuals that would remain after remediation will be addressed in this section.

Alternative 1 - No Action

If the no-action alternative is pursued, there would be some reduction in the toxicity and volume of the contaminant plume due to natural degradation. It is expected, however, that this would be negligible when compared to the total volume of the plume. No action also would not impact the mobility of the plume as that is dependent on aquifer and contaminant characteristics. TCE and its degradation products would continue to migrate and spread further with little to no degradation evident.

Alternative 2 - Institutional Controls

This alternative would decrease the mobility and volume of the plume in the Paluxy aquifer by lowering the groundwater velocities through cessation of pumping. Toxicity would not be affected, nor would the type and quantity of residuals, as no remediation would occur.

Alternative 3 - Dissolved Plume Pump and Treat

The goal of the extraction system is the reduction of the mobility and volume of the plume by controlling plume movement by pumping and removing the contaminated groundwater to treatment

facilities. In addition, the wells currently screened in the Paluxy are likely sources of leakage from the Upper Zone flow system. These wells, P-22M and P-22U, would be plugged to prevent any possible further contamination.

4.2.1.5 Short-Term Effectiveness

Evaluation of short-term effectiveness addresses effects of construction and implementation of the alternative until the RAOs have been achieved. The effect of remediation activities on human health and the environment are assessed. The evaluation considers protection of the community and worker protection during construction, maintenance, and monitoring. Adverse effects on the environment due to construction and the reliability of mitigative measures in preventing or reducing impact also are considered. Lastly, estimated project life or length of time to achieve the RAOs is evaluated.

Alternative 1 — No Action

During the short-term, there would be no risk to the community or current employees at the site. If left unmitigated, it is expected from the modelling, that the plume would eventually reach the potable wells in White Settlement. Risks, therefore, do exist, but due to distance they are not expected to affect the community for several years. The no-action alternative may achieve some of the RAOs at the site due to plume migration and minor attenuation, but would not meet all objectives.

Alternative 2 - Institutional Controls

Drilling production wells to the aquifer below the Paluxy is not expected to have any adverse effects on human health or the environment as no hazardous chemicals are expected to be found. It is expected that the wells could be constructed and in production within six months to a year.

Alternative 3 - Dissolved Plume Pump and Treat

Installation of the extraction system may affect employees of the plant but not the community of White Settlement due to distance. Possible risks to workers may include inadvertent contact with materials during the various phases of construction for the pumping wells and trenching for influent and effluent lines. A line break is considered unlikely as this usually occurs from over pressure or freezing, neither of which is considered likely. Exposure risks can be minimized by coordination of remediation activities with plant supervisors, barricading and marking construction areas, and working in high-traffic areas during off-peak hours. Activities associated with closing the two wells in the Paluxy West plume are not expected to cause any special health hazards. Specific activities to limit exposure probability would be addressed when a remediation method has been chosen.

4.2.1.6 Implementability

Alternative 1 — No Action

Technical Feasibility — This alternative presents no technical concerns or problems as it entails no action.

Administrative Feasibility — This would require acceptance from the regulatory agencies and the local community that the groundwater contamination would not be remediated and may impact potable wells in time.

Availability of Services and Materials — This is not an issue with the no-action alternative.

Alternative 2 - Institutional Controls

Technical Feasibility — It is technically feasible to triple case the production wells such that there would be no communication between the aquifers thus preventing cross-contamination.

Administrative Feasibility — Prior to the production wells being drilled, applications must be filed with the state Water Engineer to have water rights allocated and permits for the wells granted. This approval would depend upon the current use versus aquifer storage. The water quality and production rates would also have to be verified.

Availability of Services and Materials — Several drilling companies are available to perform the drilling task outlined here and they would also be able to provide sufficient materials to properly install the wells. The effort involved in attaching the wells to the distribution system also presents no difficulty to a plumbing contractor.

Alternative 3 - Dissolved Plume Pump and Treat

Technical Feasibility — The placement of the extraction wells may cause problems if the optimum location conflicts with current usage or facilities (i.e. heavily used roadways, underground utilities). The actual drilling should pose no problems as evidenced by the numerous wells currently on-site. Closure of two wells is also not expected to cause any problems as this is a common activity.

Difficulties may arise when placing piping for the pumping systems that would be required for this alternative. Plant 4's underground utilities are extensive. Delays can be expected as piping routes are designed and then changed when uncharted underground utility lines are encountered. Other delays can be expected during construction as design assumptions are proved incorrect.

Discharging to a POTW and then to receiving waters should not provide any technical challenges as it would be incorporated into the existing system.

Administrative Feasibility — The administrative issues would center around on-site construction permits.

Availability of Services and Materials — Services and materials to construct the required facilities and piping are readily available. This should not require any special procurement.

4.2.1.7 Cost

Estimated costs for the alternatives should cover all facets of the operation. Areas to be considered are capital construction costs including: construction, materials, equipment, services and annual O&M costs, such as operating labor, maintenance, disposal, administrative, and licenses. Accuracy of the estimates should be considered as well as present worth analysis, if the expenditures of an alternative occur over a period of time. This would provide a method of comparison between alternatives. As

specified in the NCP, the cost analysis prepared represents a +50/-30% degree of accuracy. The general assumptions for each alternative are outlined below. Additional details may be found in Appendix B.

All major costs for capital equipment such as pumps and remediation facilities are from current vendors as are the drilling costs. The remainder of the costs such as the piping, piping layout construction, and general labor have been calculated using the Means Construction Costing guide, experience, and bids.

Alternative 1 — No Action

Monitoring costs are the only costs associated with the no action alternative.

Total Present Worth of Alternative 1	\$274,000
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Assumptions associated with the cost estimate are:

1. Monitoring will occur for as long as contamination remains on-site, which is more than 100 years. A duration of 50 years was used to discount monitoring costs for the present worth calculation because discounting costs more than 50 years does not significantly affect the present worth.
2. Yearly monitoring will involve sampling from 15 wells with each well sampled annually for VOCs. Each sample round will cost \$15,000 (15 wells x \$1,000/well = \$15,000).
3. Present Worth Cost of Alternative:
 - Present worth based on monitoring for 50 years, discount rate of 5%.
 - Present worth = annual monitoring costs * (P/A, 50 years, 5%)
 - = \$15,000 * (18.256)
 - = \$273,840

Alternative 2 - Institutional Controls

The cost of Alternative 2, providing an alternate water supply, is given below.

Capital Cost	\$663,000
Present Worth of Monitoring Costs	\$274,000
Total Present Worth of Alternative 2	\$937,000

Capital costs include drilling and installation of all seven production wells currently serving White Settlement, pumping equipment, one round of sampling, and sufficient piping to attach to the existing distribution system. O&M costs for the well system would be covered by the city of White Settlement. A breakdown of capital costs is found in Appendix B.

Assumptions associated with the cost estimate are:

1. The new wells will be placed as near as possible to the old wells to minimize pipe connections to the distribution system.
2. One round of sampling will be done to verify potability and will include standard water treatment parameters and VOCs.
3. Pumps will operate at the same rate as previous pumps (50 to 60 gpm).
4. No additional treatment shall be needed for the water other than what is currently being performed at the White Settlement water treatment facility.
5. Monitoring will occur for as long as contamination remains on-site, which is more than 100 years. A duration of 50 years was used to discount monitoring costs for the present worth calculation because discounting costs more than 50 years does not significantly affect the present worth.
6. Yearly monitoring will involve sampling from 15 wells with each well sampled annually for VOCs. Each sample round will cost \$15,000 (15 wells x \$1,000/well = \$15,000).
7. Present Worth Cost of Monitoring:

Present worth of monitoring based on monitoring for 50 years, discount rate of 5%.

Present worth = annual monitoring costs * (P/A, 50 years, 5%)

= \$15,000 * (18.256)

= \$273,840

Alternative 3 - Dissolved Plume Pump and Treat

Physical Treatment

The cost of Alternative 3 with physical treatment is given below.

Extraction System with Physical Treatment Cost	\$1,770,000
Present Worth of O&M Costs	\$211,000
Present Worth of Monitoring	\$559,000
Total Present Worth of Alternative 3 with Physical Treatment	\$2,541,000

The total present worth cost of the alternative will be \$3,054,000 if either the East Parking Lot Alternative 1 or Alternative 2 is chosen as the preferred alternative (rather than East Parking Lot Alternative 3). This is because containment activities in the Paluxy Upper Sand would be required for longer than 15 years. The estimate shown above reflects a 15 year time period for containment activities in the Paluxy Upper Sand.

Capital costs include: groundwater pumping well installations, treatment system installations, associated piping from pumping wells to treatment systems then to discharge, and electrical connections. O&M costs would include electrical requirements, water sampling for compliance and mass distribution estimates, equipment maintenance and replacement when necessary, and monitoring during the project life. A breakdown of capital costs is found in Appendix B.

Assumptions associated with the cost estimate are:

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1. Three wells will be installed (EX-1, EX-2, and EX-3). EX-2 will have a saturated thickness of 15 feet while EX-3 will be 5 feet. Contaminant levels will be 1,000 $\mu\text{g/L}$ and 100 $\mu\text{g/L}$, respectively.
2. Wells P-8US, P-9US, P-14US, P-15US, P-16US will be pumped at 19 gpm, EX-3 will be 1 gpm.
3. TCE concentrations from Paluxy Upper Sand wells sampled in 1992 will not vary from proposed round of sampling by more than 20 percent.
4. The three new wells (EX-1, EX-2, and EX-3) will be drilled 75 feet deep, double cased, with 10 feet of screen. Wells placed in the Paluxy aquifer and Paluxy Upper Sand will be double cased to prevent further vertical migration between aquifers. The first well casing will be of steel and a minimum of 13 $\frac{5}{8}$ inches outside, and the inside would be Schedule 40 PVC with an inside diameter of 8 inches.
5. No DNAPL will be encountered.
6. TCE contaminated water volume shall be computed from 1992 sampling as shown on Figures II-19a, II-19b, II-19c, and II-19d of the RI Report. This will produce an average TCE concentration of 700 $\mu\text{g/L}$ over a revised contaminated volume of 3.8×10^7 gallons. Porosity is assumed to be 25 percent.
7. A pump/slug test will verify these pump rates as correct. Pumping rates have been estimated based upon information from the RI. They are estimates only. Pump/slug tests costs have been included.
8. For the Paluxy Upper Sand Plume, one air stripper operating at 135 gpm to remove an average TCE concentration of 700 $\mu\text{g/L}$.
9. Paluxy Upper Sand wells will require a 2.5 HP stainless steel submersible pump operating at 19 gpm. Paluxy West wells will require a 5 HP stainless steel, submersible pump which will operate at 45 gpm.
10. The Paluxy West Plume will have 1 well pumping at 45 gpm with 1 air stripper operating at 45 gpm to remove an average TCE concentration of 60 $\mu\text{g/L}$.
11. Double contained piping for the influent will consist of TCE-impervious hose with PVC Schedule 40 outer piping. Hose diameter for Paluxy wells will be 3 inch inside diameter with 6 inch PVC.
12. Costs of applicable permits have not been included.
13. Costs for treatability studies have not been included.

14. Paluxy West Plume Monitoring
For the Paluxy West plume wells and well P-8UN, the annual monitoring costs will be \$20,000 (quarterly sampling of 5 wells @ \$1,000/sample) for 5 years (3 years of remediation plus 2 years post monitoring). For years 6-8, monitoring will include 5 wells, semi-annually. The annual cost will be \$10,000.
15. Present Worth Cost for Paluxy West Plume Monitoring:

$$\begin{aligned}\text{Present worth cost} &= A1(P/A, 5 \text{ yrs}, 5\%) + A2(P/A, 3 \text{ yrs}, 5\%)(P/F, 5 \text{ yrs}, 5\%) \\ &= \$20,000 \times 4.329 + \$10,000 \times 2.723 \times 0.7835 \\ &= \$107,914.\end{aligned}$$
16. Present Worth Cost for Paluxy West Plume O&M:
Annual O&M costs are shown in the cost worksheet.

$$\begin{aligned}\text{Present worth cost} &= \text{annual O\&M costs} \times (P/A, 3 \text{ years}, 5\%) \\ &= \$9,000 \times 2.723 \\ &= \$24,507\end{aligned}$$
17. Paluxy Upper Sand Monitoring
The annual monitoring costs will be \$40,000 (quarterly monitoring of 10 wells, \$1,000/sample).
18. Present Worth Cost for Paluxy Upper Sand Monitoring
100 Year Project Life (required for East Parking Lot Plume, Alternative 2)

$$\begin{aligned}\text{Present worth cost} &= \text{annual monitoring costs} \times (P/A, 100 \text{ years}, 5\%) \\ &= \$40,000 \times 19.848 \\ &= \$793,920\end{aligned}$$

15 Year Project Life (required for East Parking Lot Plume, Alternative 3)
Monitoring assumed to continue for 2 years after remediation is complete; total monitoring time is 17 years.

$$\begin{aligned}\text{Present worth costs} &= \text{annual monitoring costs} \times (P/A, 17 \text{ years}, 5\%) \\ &= \$40,000 \times 11.274 \\ &= \$450,960\end{aligned}$$
19. Present Worth Cost for Paluxy Upper Sand O&M:
100 Year Project Life (required for East Parking Lot Plume, Alternative 2)

$$\begin{aligned}\text{Present worth costs} &= \$18,000 \times (P/A, 100 \text{ yrs}, 5\%) \\ &= \$18,000 \times 19.848 \\ &= \$357,264\end{aligned}$$

15 Year Project Life (required for East Parking Lot Plume, Alternative 3)

$$\begin{aligned}\text{Present worth costs} &= \$18,000 \times (P/A, 100 \text{ yrs}, 5\%) \\ &= \$18,000 \times 10.380 \\ &= \$186,840\end{aligned}$$
20. P-22U and P-22M in the Paluxy West plume will be plugged.
21. The Paluxy West Plume with 5.4×10^7 gallons to be removed (10 times the volume of contaminated groundwater) can be extracted with four wells in approximately one year.

22. No site preparation required, such as grading or road construction.
23. A 6-inch slab-on-grade with containment will be the treatment plant foundation.
24. Treatment plants are package units which can be placed directly on poured slabs. They will be prefabricated units that will only require influent, effluent, and electrical hookups.
25. Drill cuttings from pumping wells would be stockpiled and a portion sent for disposal analysis, with the entire amount being accepted for disposal at an off-site plant.
26. Double contained piping for the influent are to consist of TCE-impervious hose with PVC Schedule 40 outer piping. Hose diameter for Paluxy wells is to be 3 inch inside diameter, 6 inch PVC.
27. Additional wells will be installed and located to help define the downgradient plume extent for both the Paluxy aquifer and Paluxy Upper Sand groundwater. Costs for installation of new wells are included with capital costs.
28. Present Worth Cost (based on 100 year project life)

Capital Costs	\$1,770,495
Paluxy West Plume O&M Costs	\$24,507
Paluxy Upper Sand Plume O&M Costs	\$357,264
Paluxy West Plume Monitoring Costs	\$107,914
Paluxy Upper Sand Plume Monitoring Costs	\$793,920
Total Present Worth Cost	\$3,054,100

 Present Worth Cost (based on 15 year project life)

Capital Costs	\$1,770,495
Paluxy West Plume O&M Costs	\$24,507
Paluxy Upper Sand Plume O&M Costs	\$186,840
Paluxy West Plume Monitoring Costs	\$107,914
Paluxy Upper Sand Plume Monitoring Costs	\$450,960
Total Present Worth Cost	\$2,540,716

Chemical Treatment

The cost of Alternative 3 with chemical treatment is given below.

Extraction System with Chemical Treatment Cost	\$2,091,000
Present Worth of O&M Costs	\$451,000
Present Worth of Monitoring Costs	\$559,000
Total Present Worth of Alternative 3 with Chemical Treatment	\$3,101,000

The total present worth cost of the alternative will be \$3,804,000 if either the East Parking Lot Alternative 1 or Alternative 2 is chosen as the preferred alternative (rather than East Parking Lot Alternative 3). This is because containment activities in the Paluxy Upper Sand would be required for longer than 15 years. The estimate shown above reflects a 15 year time period for containment activities in the Paluxy Upper Sand.

The assumptions are the same as those listed under Alternative 3 that uses Air Stripping with the exception of those listed below:

1. For the Paluxy Upper Sand Plume, 1 UV/ozone unit operating at 135 gpm to remove an average TCE concentration of 700 µg/L.
2. The Paluxy West Plume will have 1 UV/ozone unit operating at 180 gpm to remove an average TCE concentration of 60 µg/L.
3. Present Worth Cost for Paluxy West Plume O&M:
Annual O&M costs are shown in the cost worksheet.
Present worth costs = annual O&M costs x (P/A, 3 years, 5%)
= \$21,000 x 2.723
= \$57,183
4. Present Worth Cost for Paluxy Upper Sand O&M:
100 Year Project Life (required for East Parking Lot Plume, Alternative 2)
Present worth costs = \$38,000 x (P/A, 100 yrs, 5%)
= \$38,000 x 19.848
= \$754,224

15 Year Project Life (required for East Parking Lot Plume, Alternative 3)
Present worth costs = \$38,000 x (P/A, 100 yrs, 5%)
= \$38,000 x 10.380
= \$394,440
5. Present Worth Cost (based on 100 year project life)

Capital Costs	\$2,090,957
Paluxy West Plume O&M Costs	\$ 57,183
Paluxy Upper Sand Plume O&M Costs	\$ 754,224
Paluxy West Plume Monitoring Costs	\$ 107,914
Paluxy Upper Sand Plume Monitoring Costs	\$ 793,920
Total Present Worth Cost	\$3,804,198

 Present Worth Cost (based on 15 year project life)

Capital Costs	\$2,090,957
Paluxy West Plume O&M Costs	\$ 57,183
Paluxy Upper Sand Plume O&M Costs	\$ 394,440
Paluxy West Plume Monitoring Costs	\$ 107,914
Paluxy Upper Sand Plume Monitoring Costs	\$ 450,960
Total Present Worth Cost	\$3,101,454

4.2.2 Upper Zone East Parking Lot Plume Alternatives

Three alternatives were developed for contamination in the East Parking Lot Plume. One alternative was the no-action alternative, as required by the NCP. Another alternative was to use traditional pumping methods to extract the contaminated groundwater and DNAPL until cleanup levels are reached and treat the groundwater with air stripping, UV oxidation, or biological treatment. The third

alternative is to enhance extraction that uses surfactants to remove the contaminated groundwater and DNAPL and treat the groundwater with air stripping.

4.2.2.1 Overall Protection of Human Health and the Environment

Alternative 1 - No Action

The no-action alternative would result in a decrease in concentrations measured across the site over time. TCE would continue to diffuse through the Window Area into the Paluxy which may impact the potable wells in White Settlement. Some degradation due to natural degradation would likely occur but the majority would be dispersed from the plume as it migrates with the groundwater flow. This alternative does not adequately provide any control or reduction in risk. It does not attempt to reduce or eliminate the plume which would attempt to control exposure. This has been supported in the BRA, which concludes that sufficient quantities of contaminants exist that must be remediated as they would present an unacceptable health risk.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

The groundwater extraction system would reduce TCE concentrations to acceptable levels by increasing the groundwater velocity and therefore increasing the amount of TCE in solution. Using upgradient injection of clean water would also increase velocities and removal rates. The overall protection of this method is poor as the projected amount of time for the DNAPL pools to dissolve is measured in hundreds of years. During this time, DNAPL would continue to diffuse through the Walnut Formation in the Window Area to the Paluxy, causing remedial activities to continue there also.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

By first locating the DNAPL through tracers, then targeting the DNAPL through surfactants designed for the site, the DNAPL would be removed which continues to act as a source for more dissolved TCE. This alternative would increase the dissolved fraction of DNAPL thus increasing removal rates of DNAPL through the extraction system. After the source is removed, a slurry wall may be installed upgradient of the Window Area. This would alter the direction and amount of contaminated water flowing to the Window Area. The extraction system would then remove the remaining dissolved DNAPL around the Window Area.

4.2.2.2 Compliance with ARARs

Alternative 1 - No Action

Failure to perform remedial action at Air Force Plant 4 would result in non-compliance with Federal and state regulatory requirements. Selection of this alternative would result in violation of the SDWA, National Primary and Secondary Drinking Water Standards (40 CFR 141 and 143) and the TAC, Title 31, Part IX, Chapter 290 (Texas Drinking Water Standards). Because it appears likely that TCE could contaminate White Settlement potable water wells within 60 years, this alternative is not considered feasible.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Discharge of the treated groundwater would be to a POTW or to receiving surface waters when NPDES compliance can be demonstrated. The discharge system would comply with regulated permits. The construction of the slurry wall with DNAPL resistant materials should not pose a regulatory problem as such materials are already in use in concrete projects.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Approval for the addition of surfactants into the groundwater would be considered on a case by case basis. It is not prohibited but cannot adversely affect water quality (Subchapter D, Section 26.121 of the Texas Water Quality Act) and must include engineering controls suitable to the activity. Discharge of the treated groundwater would first be to a POTW, then to receiving surface waters once compliance with NPDES is demonstrated.

4.2.2.3 Long-Term Effectiveness and Permanence

The primary focus is to address the results of the remedial action in terms of the risk remaining after the RAOs have been met. The effectiveness and reliability of the alternative and the residual risk of untreated waste should be considered.

Alternative 1 - No Action

Since this method does not propose treatment or remediation methods and sources and exposure routes have been defined, this solution would not be effective in the future, nor is it a permanent solution. Since no-action would be anticipated under this alternative, the risk factors derived under the assessment would be expected in the future. Eventually, however, the risk is expected to diminish due to natural degradation of the contaminants.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

The extraction system would eventually remove all the DNAPL to acceptable levels by removing the DNAPL as it dissolves. Injection wells would enhance the process somewhat by increasing velocities as would the slurry wall by halting more DNAPL movement from impacting the Window Area. This method would inadequately protect the Window Area, i.e., halt vertical migration of dissolved contaminants into the Paluxy until all of the DNAPL has dissolved.

Suitable controls and maintenance would prevent exposure due to equipment failure. If the pump equipment and wells are properly maintained, they would retain their performance specifications. Maintenance should be scheduled to provide optimum system operation without causing severe delays and system shutdown. It is expected that parts would need to be replaced due to wear, but would be included as part of the regular O&M. Controls on the extraction system would affect pump operation to prevent damage to the pump and system failure. If needed, the system could be designed with redundancies in the event of a control failure.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

The efficacy of surfactants is dependent upon locating the DNAPL, usually through a tracer test which would locate the DNAPL and quantify it. The reliability would be dependent upon the specific chemical used. This enhancement technology would have no residual risk as no wastes would be left untreated. The extraction system would remove the dissolved TCE with the surfactants through pumping. The surfactants would then be recovered and the water treated.

Suitable controls and maintenance would prevent exposure due to equipment failure. If the pump equipment and wells are properly maintained, they would retain their performance specifications. Maintenance should be scheduled to provide optimum system operation without causing severe delays and system shutdown. It is expected that parts would need to be replaced due to wear, but would be included as part of the regular O&M. Controls on the extraction system would affect pump operation to prevent damage to the pump and system failure. If needed, the system could be designed with redundancies in the event of a control failure.

4.2.2.4 Reduction of Toxicity, Mobility, or Volume Through Treatment***Alternative 1 - No Action***

If the no-action alternative is pursued, there would be some reduction in the toxicity and volume of the contaminant plume due to natural degradation. It is expected, however, that this would be negligible when compared to the total volume of the plume. No-action also would not impact the mobility of the plume as that is dependent on aquifer and contaminant characteristics. TCE and its degradation products would continue to migrate and spread further with little to no degradation evident.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

The goal of the extraction/injection system is the reduction of the mobility and volume of the plume by controlling plume movement. This would be accomplished by pumping and removing the contaminated groundwater to treatment facilities. The remaining dissolved TCE and its degradation products would be below the required 250 µg/L in the Window Area and 10,000 µg/L in the source area.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Surfactants would permit the timely removal of the TCE DNAPL. Groundwater extraction would produce an irreversible process. The residuals would be dissolved DNAPL below the PRG of 250 µg/L in the Window Area and 10,000 µg/L in the source area. Residuals would continue to degrade but should not pose a risk as the levels would be below the acceptable range for the Upper Zone PRG's.

4.2.2.5 Short-Term Effectiveness

Alternative 1 - No Action

During the short-term, there would be no risk to the community or current employees at the site. If left unmitigated, contaminants would continue to diffuse into the Paluxy, continuing to contribute more contamination. The plume in the Paluxy would eventually reach the potable wells in White Settlement. Risks, therefore, do exist, but due to distance they are not expected to affect the community for several years. The no-action alternative may achieve some of the RAOs at the site due to plume migration and minor attenuation, but would not meet all objectives.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Installation of the extraction/injection system may affect employees of the plant but not the community of White Settlement due to distance. Possible risks to workers may include inadvertent contact with materials during the various phases of construction of the pumping wells and trenching for influent and effluent lines. A line break is considered unlikely as this usually occurs from over pressure or freezing, neither of which is considered likely. Exposure risks are expected to be low through coordination of remediation activities with plant supervisors, barricading and marking construction areas, working in high-traffic areas during off-peak hours. Specific activities to limit exposure probability would be addressed when a remediation method has been chosen.

From the TCE concentrations in the source and Window Areas, it is believed that DNAPL is present. Concentrations range from 15,000 $\mu\text{g/L}$ to 180,000 $\mu\text{g/L}$ (Figures II-12 to II-14 of the RI Report). This is approximately one to twenty percent of TCE's solubility of approximately 1,000 mg/L (Verschuere 1983). Research has shown a high probability of DNAPL where dissolved concentrations range in the percent concentration of the solubility (EPA 1992).

The project life was determined from the amount of time estimated for the DNAPL TCE to dissolve. The Johnson and Pankow equation was used to estimate time for TCE to dissolve. This equation accounts for the quantity of DNAPL by using the length of the DNAPL pool, the chemical characteristics of the contaminant, aquifer parameters, and the extraction effects (Appendix C).

The pumping rate for the Upper Zone flow system has been determined from information in the RI, specifically the saturated thickness, hydraulic conductivity, and porosity (Appendix C). Parameters such as saturated thickness, TCE concentration, porosity, and hydraulic conductivity have been averaged over the area of concern. The result is an average pumping rate and TCE concentration. Aquifer testing should be considered to determine more accurate aquifer parameters and contaminant concentration and location. Also, modelling of the aquifer has not been completed which could impact the pumping rate and costs. For example, if the model shows that conductivities are lower than assumed, the time to remediation could be longer, resulting in higher than estimated costs.

A minimum of ten extraction and ten injection wells pumping at 5 gpm would sufficiently cover the DNAPL area under Building 181 and the Window Area. The enhanced and non-enhanced extraction/injection systems have the same number of wells to provide an easier method of comparison. Dissolving and removing the TCE is expected to last over 100 years and remove over 2.6 billion gallons of TCE-contaminated water.

The treated water is expected to first be discharged to the local POTW while verifying the ability of the system to meet NPDES discharge requirements. Once this is completed, discharge would be to surface water.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Installation of the extraction system may affect employees of the plant but not the community of White Settlement due to distance. Possible risks to workers may include inadvertent contact with materials during the various phases of construction for the pumping wells and trenching for influent and effluent lines. A line break is considered unlikely as this usually occurs from over pressure or freezing, neither of which is considered likely. Exposure risks are expected to be low through coordination of remediation activities with plant supervisors, barricading and marking construction areas, working in high-traffic areas during off-peak hours. Exposure to surfactants is not considered to be hazardous as many are food grade additives and are therefore, non-toxic. Specific activities to limit exposure probability would be addressed when a remediation method has been chosen.

From the TCE concentrations in the source and Window Areas, it is believed that DNAPL is present. Concentrations range from 15,000 µg/L to 180,000 µg/L (Figures II-12 to II-14 of RI Report). This is approximately one to twenty percent of the solubility of TCE which is 1,000 mg/L (Verschueren 1983). Research has shown a high probability of DNAPL where dissolved concentrations range in the percent concentration of the solubility (EPA 1992).

The surfactant project consists of two parts: a partitioning tracer test and DNAPL extraction. The tracer test would determine if DNAPL is present, its location, quantity and site-specific surfactant testing and development. With the initial stage completed, extraction of the DNAPL would be begin. Due to the nature of surfactants, only air stripping can be used to treat the water as the contaminant must first be removed before the surfactant can be recovered. Other water treatment methods would degrade the surfactants while destroying the contaminants and as surfactants are expensive, recovery and re-use is preferred. The surfactant enhanced DNAPL removal is expected to last approximately 12-15 years. Information on the surfactant strategy and project life was compiled from literature and conversations with industry experts. Aquifer testing should be considered to determine more accurate aquifer and contaminant parameters.

The treated water is expected to first be discharged to the local POTW while verifying the ability of the system to meet NPDES discharge requirements. Once this is completed, discharge would be to surface water.

4.2.2.6 Implementability

Alternative 1 - No Action

Technical Feasibility: This alternative presents no technical concerns or problems as it entails no action.

Administrative Feasibility: This would require acceptance from the regulatory agencies and the local community that the groundwater contamination would not be remediated and may impact potable wells in time.

Availability of Services and Materials: This is not an issue with the no-action alternative.

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Technical Feasibility: The placement of the extraction and injection wells may cause problems if the optimum location conflicts with current usage or facilities (i.e. heavily used roadways, underground utilities). The actual drilling should pose no problems as evidenced by the numerous wells currently on-site. Construction of the slurry wall, if DNAPL resistant materials are not used and it is not continuous, would be ultimately ineffective.

Difficulties may arise when placing piping for the pumping systems that would be required. Delays can be expected as piping routes are designed and then changed when uncharted underground utility lines are encountered. Other delays can be expected when interim remediation systems not considered in the RI/FS, due to lack of knowledge or incomplete information, alter the groundwater flow system.

Discharge to a POTW and then to receiving waters should not provide any technical challenges as it would be incorporated into the existing system.

Administrative Feasibility: The administrative issues would center around on-site construction permits.

Availability of Services and Materials: Services and materials to construct the required facilities and piping are readily available. This should not require any special procurement.

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Technical Feasibility: The placement of the extraction wells may cause problems if the optimum location conflicts with current usage or facilities (i.e. heavily used roadways, underground utilities). The actual drilling should pose no problems as evidenced by the numerous wells currently on-site. The slurry wall construction, after the DNAPL has been removed, should present no technical difficulties.

The technical issues of using surfactants would greatly depend upon whether the DNAPL source areas can be accurately located and whether the chosen surfactant is effective in the removal of TCE. A tracer test would be used to locate and quantify the DNAPL. Laboratory testing would produce a tracer suite specialized for this application. The methodology to deliver and extract the DNAPL recovery chemicals are merely hydraulic control strategies which are in common use.

Difficulties may arise when placing piping for the pumping systems. Delays can be expected as piping routes are designed and then changed when uncharted underground utility lines are encountered. Other delays can be expected when interim remediation systems not considered in the RI/FS, due to lack of knowledge or incomplete information, alter groundwater flow.

Discharge to a POTW and then to receiving waters should not provide any technical challenges as it would be incorporated into the existing system.

Administrative Feasibility: The administrative issues would center around on-site construction permits and injection permits.

Availability of Services and Materials: Services and materials to construct the required facilities and piping are readily available. This should not require any special procurement.

4.2.2.7 Cost

Alternative 1 - No Action

The cost associated with the no-action alternative only includes monitoring costs.

Total Present Worth of Alternative 1 \$822,000

Assumptions associated with the cost estimate are:

1. Monitoring assumes that 45 samples will be taken annually. Samples will be both surface water and groundwater samples. Each sample will be analyzed for VOCs. Cost per sample = \$1,000. Annual cost of monitoring = 45 samples x \$1,000/sample = \$45,000
2. Monitoring will occur for as long as contamination remains on-site, which is more than 100 years. A duration of 50 years was used to discount monitoring costs for the present worth calculation because discounting costs more than 50 years does not significantly affect the present worth.
3. Present worth of monitoring is based on monitoring costs of \$45,000/year for 50 years with a discount rate of five percent. The present worth of monitoring cost is the present worth of the alternative costs.

$$\begin{aligned}
 \text{Present worth of No Action} &= \$45,000 * (P/A, 50 \text{ years}, 5\%) \\
 &= \$45,000 * (18.256) \\
 &= \$821,520
 \end{aligned}$$

Alternative 2 - Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

Two cost estimates for Alternative 2 are provided below, one for each type of treatment process.

Physical Treatment:

The costs of Alternative 2 with physical treatment are:

Capital Cost	\$4,071,000
Present Worth of O&M Costs	\$913,000
Present Worth of Monitoring Costs	\$1,898,000
Total Present Worth of Alternative 2 with Physical Treatment	\$6,882,000

Capital costs include treatment system installations, associated piping from wells to treatment systems to discharge point, and electrical connections. O&M costs would include electrical requirements, water sampling for compliance and mass distribution estimates, equipment maintenance, and replacement when necessary. A breakdown of capital costs is provided in Appendix B.

Assumptions associated with the cost estimate are:

1. No site preparation required, such as grading or road construction.
2. A 6-inch slab-on-grade will be the treatment plant foundation.
3. Treatment plants are package units which can be placed directly on poured slabs. They will be prefabricated units that will only require influent, effluent, and electrical hookups.
4. Ten extraction and 10 injection wells will be installed to pump at 5 gpm, 1 air stripper will be installed to operate at 50 gpm and remove an average of 20,000 $\mu\text{g/L}$ TCE to 250 $\mu\text{g/L}$ TCE in the Window Area and 10,000 $\mu\text{g/L}$ under Building 181.
5. Double contained piping for the influent to consist of TCE-impervious hose with PVC Schedule 40 outer piping. For Upper Zone wells, one-inch inside diameter hose will be used with three-inch PVC outer piping.
6. Costs of applicable permits have not been included.
7. Treatability studies will not be required.
8. The project life is over 100 years but a time period of 50 years was used to discount O&M costs and monitoring costs for the present worth calculation. Discounting costs for a period longer than 50 years provides an insignificant increase in the present worth.
9. An additional 20 wells will be installed to monitor plume migration. These will be installed in year one. The cost associated with these wells will be \$72,000 (40 feet deep, \$90/LF, 20 wells).
10. The soil excavated for slurry wall construction will be uncontaminated as installation will not occur until DNAPL has been removed. The soil will be disposed in a local sanitary landfill.
11. Aquifer testing will be performed.
12. DNAPL, if any is collected through the oil/water separator, will be disposed as hazardous waste.
13. Annual Monitoring:
For monitoring the East Parking lot plume, 10 wells will be sampled quarterly for the life of the project. The annual cost will be $4 \times 10 \text{ wells} @ \$1,000/\text{sample} = \$40,000$. The perimeter will also be monitored. Perimeter monitoring would involve thirty wells sampled semi-annually for the life of the project (5 wells in the North plume, 5 wells in the West plume and 20 wells inside and outside the East plume). The annual cost of perimeter monitoring will be \$60,000 (30 wells \times 2 \times \$1,000/sample). Total annual monitoring cost = \$40,000 + \$60,000 = \$100,000.

14. Present Worth Cost of Monitoring:

Present worth cost of monitoring includes additional monitoring well installation costs of \$72,000 that occur in year one (see item 9).

$$\begin{aligned}\text{Present Worth of Monitoring} &= \$100,000 \times 18.256 + \$72,000 \text{ (well installation in year 1)} \\ &= \$1,825,600 + \$72,000 \\ &= \$1,897,600\end{aligned}$$

15. Present Worth Cost of O&M:

Present worth costs are discounted based on 50 years project life and a discount rate of 5%. Annual O&M costs are determined in the cost worksheet.

$$\begin{aligned}\text{Present worth of O\&M costs} &= \text{annual O\&M costs} * (P/A, 50 \text{ years}, 5\%) \\ &= \$50,000 * (18.256) \\ &= \$912,800\end{aligned}$$

Chemical Treatment

The cost of Alternative 2 with chemical treatment are:

Capital Cost	\$4,231,000
Present Worth of O&M Costs	\$1,205,000
Present Worth of Monitoring Costs	\$1,898,000
Total Present Worth of Alternative 2 with Chemical Treatment	\$7,334,000

Capital costs include treatment system installations, associated piping from wells to treatment systems to discharge point, and electrical connections. O&M costs would include electrical requirements, water sampling for compliance and mass distribution estimates, and equipment maintenance and replacement when necessary. Assumptions made in the cost estimate are necessarily the same with regards to the discharge, therefore, all assumptions listed under Alternative 2 Physical Treatment should be included here with the exception of number five which addresses air stripper requirements.

The assumptions are the same as those listed under Air Stripping Treatment with the exception of those listed below:

1. Assumptions included in the cost estimate are that the Window Area and source area under Building 181 will require 10 extraction and 10 injection wells to be installed to pump/inject at five gpm. One UV/Oxidation unit will be installed to operate at 50 gpm and remove an average of 20,000 µg/L TCE to 250 µg/L TCE in the Window Area and 10,000 µg/L in the source area.
2. Present worth of monitoring costs is the same as for physical treatment.
3. Present worth of O&M costs based on a discount rate of 5%.

$$\begin{aligned}\text{Present worth of O\&M costs} &= \text{annual O\&M costs} * (P/A, 50 \text{ years}, 5\%) \\ &= \$66,000 * (18.256)\end{aligned}$$

Alternative 3 - Enhanced Source Removal/Window Area Dissolved Plume Remediation Combined with Containment

The cost estimate for Alternative 3 is given below. Only one cost estimate is provided since physical treatment (air stripping) is the only treatment option considered for this alternative.

Capital Cost	\$7,603,000
Present Worth of O&M Costs	\$1,062,000
Present Worth of Monitoring Costs	\$1,199,000
Total Present Worth of Alternative 3	\$9,865,000

Capital costs include treatability testing, treatment system installations, associated piping from treatment systems to discharge, and electrical connections. O&M costs would include electrical requirements, water sampling for compliance and mass distribution estimates, and equipment maintenance and replacement when necessary. A breakdown of capital costs is found in Appendix B.

Assumptions included in the cost estimate are:

1. The Window Area and DNAPL areas will require 10 extraction and 10 injection wells to be installed to pump/inject at 5 gpm, 3 air strippers will be installed to operate at 15-20 gpm each and remove dissolved TCE. Although the flow rate is the same as for Alternative 2 with physical treatment, lower flow rates in the air stripper are required to prevent possible foaming.
2. The soil excavated for slurry wall construction will be uncontaminated as installation will not occur until DNAPL has been removed. The soil will be disposed in a local sanitary landfill.
3. For monitoring the East Parking Lot Plume, 10 wells will be sampled quarterly for the life of the project (15 years remediation plus 2 years post = 17 years). The annual cost will be 4 x 10 wells @ \$1,000/sample = \$40,000. The perimeter will also be monitored. Thirty wells will be sampled semi-annually for the life of the project (five in the North plume, five in the West plume, and 20 inside and outside the East plume) The annual cost of perimeter monitoring will be \$60,000 (30 wells x 2 sampling events/year x \$1,000/sample).

$$\begin{aligned}
 \text{Present worth of Monitoring:} &= (\$100,000 \times 11.274) + \$72,000 \text{ (well installation costs)} \\
 &= \$1,127,400 + \$72,000 \\
 &= \$1,199,400
 \end{aligned}$$

4. Present worth of O&M costs based on 15 years project life and a discount rate of 5%.

$$\begin{aligned}
 \text{Present worth of O\&M} &= \text{annual O\&M costs} * (P/A, 15 \text{ years}, 5\%) \\
 &= \$102,355 * (10.380) \\
 &= \$1,062,445
 \end{aligned}$$
5. An additional 20 wells will be installed to monitor plume migration. These will be installed in year one. The cost associated with these wells will be \$72,000 (40 feet deep, \$90/LF, 20 wells).

4.2.3 Treatment Alternatives

Evaluation of the different methods of treating extracted groundwater was performed separately because they apply to several different alternatives.

4.2.3.1 Overall Protection of Human Health and the Environment

Alternative 1 - Physical Treatment

The use of air stripping to remove dissolved volatile contaminants and an oil/water separator to remove emulsified DNAPL would adequately protect human health and the environment in both short- and long-term. Air emissions from the air stripper are regulated under TAC Guidance Document "Exemption 68."

Alternative 2 - Chemical Treatment

The major treatment would be a UV/oxidation unit with an oil/water separator to remove emulsified DNAPL and prevent a possible discharge excursion. This alternative oxidizes the molecules of the contaminants into components which are non-toxic. It does not involve changing the state of the contamination as does air stripping. It is an irreversible treatment that, through design and with proper and regular maintenance, would successfully meet the RAOs while ensuring protection of human health and the environment. It would leave no residuals and would be effective upon start-up.

4.2.3.2 Compliance with ARARs

Alternative 1 - Physical Groundwater Treatment

Removal of contaminants from the groundwater would result in compliance with Federal and state contaminant level standards. Regulatory drivers of primary concern under this alternative would be the following:

- National Primary and Secondary Drinking Water Standards (40 CFR 141 and 143). These regulations for which authority is delegated to the state of Texas are implemented under the TAC, Table 31, Part IX, Chapter 290. The TAC essentially adopts the federal standard for all contaminants of concern.
- Clean Air Act (as delegated to the state of Texas under 40 CFR 52, Subpart 55). These regulations are implemented under the TAC, Title 31, Chapter 115 and require control of volatile organic compounds. If volatilization of contaminants results in air emissions, compliance with the aforementioned state regulations would be required. The TAC, Title 31, Part III, Chapter 120, also requires control of air pollution at hazardous waste sites.
- RCRA (40 CFR 262 through 270) as implemented by TAC, Title 31, Chapter 335, Texas Industrial Waste Management Regulations. If any wastes are generated as a result of physical treatment (i.e., reserves), then appropriate state storage, treatment, and disposal requirements must be complied with. Appendix A details state requirements applicable to the generation, storage, treatment, transportation, and disposal of hazardous wastes.

- TAC Guidance Document "Exemption 68". This would provide the guidance for the air emissions from the various treatment systems. The chosen system would comply with this document.
- TAC, Title 30, Chapter 331, Underground Injection Control, is a state regulation related to injection of chemicals into non-potable aquifers to facilitate remediation; however, this would be evaluated on a case-by-case basis.

In summary, this alternative would be impacted by a combination of location, action, and chemical specific ARARs. Secondary concerns are related to location and action specific ARARs centered on the location of the pumping wells, treatment facilities, and interceptor trench. Location of the aforementioned facilities within "natural areas" in close proximity to environmentally sensitive areas (i.e., wetlands) may invoke ARARs identified in Appendix A. Secondary chemical ARARs are the CWA and possibly the Toxic Substances Control Act if PCBs are encountered.

Alternative 2 - Chemical Groundwater Treatment

This alternative would closely parallel the primary regulatory drivers described under Alternative 2 (Physical Groundwater Treatment). Compliance with state drinking water standards, hazardous waste regulations, and air quality standards remain the primary regulatory drivers.

4.2.3.3 Long-Term Effectiveness and Permanence

Alternative 1 - Physical Treatment

Air stripping provides a successful, long-term, and permanent solution. Due to the mechanisms of this alternative and an oil/water separator to facilitate the operation, it is not expected that untreated wastes would remain on-site to pose a future threat and therefore, should not be considered. The PRG is 250 $\mu\text{g/L}$ in the Window Area and 10,000 $\mu\text{g/L}$ in the source area. This alternative is expected to achieve this level. During the operation of the system, monitoring and sampling would occur as stated by the regulatory permitting agency. Sampling may include analysis of water samples for VOCs on the influent and effluent lines, and air. Annually, water sampling should include samples from a cross-section of wells for VOCs to calculate mass balance and project life. Monitoring should include meter readings (flow rates and total volume) of all individual meters and the collective meter, pressure gauge on the blower, air speed, air temperature, ambient temperature, and weather conditions. Maintenance visits should be scheduled to assess overall functionality. The system should be shut for cleaning of the major equipment (e.g. the pumps, meters, and air stripper). Any part that fails prior to inspection would either be repaired or replaced. The air stripper, however, may require additional cleaning sessions to ensure efficiency levels. The efficiency levels and air stripper size are based upon estimated total pumping rates, the contaminants and their influent concentrations, and the regulated contaminant concentration discharge limit. If concentrations increase, the system cannot be expected to maintain previously estimated removal levels and may exceed discharge limits. If this should occur, the system must be re-evaluated and possibly resized. Controls can be installed on the equipment which would prevent a discharge excursion. Such controls would shut down the system and alert maintenance crews.

Alternative 2 - Chemical Treatment

Due to the mechanisms involved in this treatment method, it would provide a permanent solution to the existing groundwater contamination problem. The method completely oxidizes compounds into non-toxic compounds. Since removal and destruction of the contaminants is the goal for this method, residual or untreated wastes are not expected to be present. It is expected that the technology would meet the expected removal rates over long term, given that it is properly maintained and operated. The water stream would be sampled on a scheduled basis. This information would be used to demonstrate discharge permit compliance, system removal efficiency, quantity removed, and a revised, estimated closure date.

Management of the system should include periodic site visits for maintenance, monitoring, and sampling. Monitoring and sampling of the system might include influent and effluent VOC concentrations, VOC emissions, ozone emissions, total organic carbon (TOC), influent ozone/hydrogen peroxide concentrations and flow rates, individual and collective meter readings (totalizer and flow rate), emissions velocity, and temperature. Annually, water samples should be collected from all pumping wells to determine mass balance and project life, as mentioned above. During these visits, the system should be shut down for general maintenance at which time the major equipment would be cleaned. This scheduled maintenance would lessen the number of emergency visits due to equipment failure. The system was designed for specific operating parameters of flow rate, influent, and effluent concentrations; should any of these change, the system should not be expected to maintain discharge standards. It may need to be re-designed and altered. Other problems, such as equipment failure, may be managed through various types of controls and sensors built into the system.

4.2.3.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Alternative 1 - Physical Treatment

The goal of air stripping is the reduction of the toxicity of the contaminant plume. The water stream is pumped into the air stripper where the contaminants are volatilized due to high energy air and dispersal. Air strippers can have efficiencies of greater than 99 percent for removal of VOCs. The efficiency of an air stripper system can be improved by actions such as increasing the height of packing material or putting air strippers in series. This is an irreversible process and would treat the total volume of dissolved contaminants. The exact efficiency required for the system would be dependent on the influent concentration and the allowable discharge concentration. This method is very common and would satisfactorily address the principal threats. No residuals are expected to remain since TCE and DCE, which would be volatilized, are the source of the residual compounds.

Alternative 2 - Chemical Treatment

The intent here mirrors the air stripping alternative where reducing toxicity, mobility, and volume are the remediation goals. From vendor information, it is expected that this method would destroy greater than 99 percent of the volatile compounds encountered. This is an irreversible process of oxidation of organic chemicals into non-toxic, less complex compounds. The major difference is that the total amount of target compounds are destroyed rather than treated, as discussed in Alternative 2. The principal threat, TCE, would be oxidized and no residuals are expected to remain requiring future remediation. This assumption is based upon the present discharge level of 250 $\mu\text{g/L}$ for TCE in the Window Area which is the more stringent requirement.

4.2.3.5 Short-Term Effectiveness

Alternative 1 - Physical Treatment

Risk of exposure from air stripping is considered low. Possible exposure may come from a line break or an emissions excursion. An emissions excursion is also considered unlikely, as an increase in dissolved organic concentrations must occur to cause the increased emissions. In this unlikely event, treatment for off-gases or lowering flow rates could be recommended.

Project life is discussed in Section 4.2.2.5. The project life is most affected by the ability to extract contaminants. The type of treatment has minimal effect on the project life.

Alternative 2 - Chemical Treatment

Risks from the UV/oxidation system may occur from emissions excursion, as discussed under Alternative 2 for the air stripper. The units are self-contained to prevent inadvertent exposure. Emissions can be quantified and measures taken to prevent excursions and exposures.

Project life is discussed in Section 4.2.2.5. The project life is most affected by the ability to extract contaminants. The type of treatment has minimal effect on the project life.

4.2.3.6 Implementability

Alternative 1 - Physical Treatment

Technical Feasibility: Air stripping is a well defined and accepted technology. The systems can either be pre-assembled or assembled on-site, depending on site requirements.

Administrative Feasibility: Emissions would comply with the TAC Guidance Document "Exemption 68."

Availability of Services and Materials: Many vendors currently provide equipment and installation services.

Alternative 2 - Chemical Treatment

Technical Feasibility: UV/oxidation has long been used for water treatment and the technology has been extended to the treatment of volatile chemicals in water. The application should present no technical problems.

Administrative Feasibility: Emissions would comply with the TAC Guidance Document "Exemption 68."

Availability of Services and Materials: Many vendors currently provide equipment and installation services.

4.2.3.7 Cost

Paluxy extraction and treatment costs are covered in Section 4.2.1.7. Extraction and treatment costs for the East Parking Lot Plume are covered in Section 4.2.2.7.

4.3 Detailed Analysis of Soil Alternatives

The detailed analysis of soil alternatives is divided into two sets of alternatives. One set of alternatives addresses the risk at Landfill No. 4, Landfill No. 3, and Meandering Road Creek. The other area for which alternatives are being developed is the vadose zone under Building 181.

4.3.1 Landfill No. 4, Landfill No. 3, and Meandering Road Creek

4.3.1.1 Overall Protection of Human Health and the Environment

Alternative 1 - No Action

The no-action alternative would not change the exposure scenarios as defined in the BRA. The risk assessment results show occupational ingestion of contaminated soil to be the only soil-driven exposure pathway that exceeded human health risk thresholds. The risk assessment also concluded that contamination exceeded ecological risk threshold values.

With regard to protecting human health, the BRA shows that benzo-a-pyrene (BAP) is the only soil contaminant that exceeded the 1.0×10^{-6} incremental lifetime cancer risk (ILCR) threshold value. BAP showed an ILCR of 1.6×10^{-6} . EPA guidance on the role of baseline risk assessments in the remedy section (EPA 1991b) states that risk levels in the range between 10^{-4} and 10^{-6} in most cases is sufficiently protective of human health. The same guidance also states that RODs for remedial actions taken at sites within the 10^{-4} and 10^{-6} risk range must explain why remedial action is warranted. Additionally, when the risk levels are calculated for the Central Tendency Evaluation, the health risk posed by the BAP in soil decreases to less than the 1.0×10^{-6} ILCR threshold value. The no-action alternative for soil can be considered protective of human health in accordance with referenced EPA guidance.

The no action is sufficiently protective of human health but may not be protective of the environment. The BRA found that contaminant levels in Landfill No. 4, Landfill No. 3, and Meandering Road Creek exceeded ecological risk threshold values. Metals in Landfill No. 4 and Landfill No. 3 were found to cause risk to mice but not to any animal that feed on the mice, such as hawks. Silver concentrations in the sediment in Meandering Road Creek and Lake Worth were found to exceed risk threshold values for aquatic organisms. The model that estimated the risk to aquatic organisms is based on a sediment quality criteria for a marine environment.

Alternative 2a - Capping (addresses human health risk)

Capping the soil contamination areas of concern should reduce the potential for human exposure to below threshold values. However, this capping alternative does not address areas of contamination that cause excess ecological risk, except for the soil at Landfill No. 4. Therefore, the exposure to mice at Landfill No. 3 and the potential for toxicity to aquatic organisms would still be present.

Alternative 2b - Excavation/Capping (addresses all risk areas)

This alternative is the same as Alternative 2a for protection of human health but also would reduce risk to ecological receptors at Landfill No. 3 and Meandering Road Creek. Ecological risk would be reduced through excavation or dredging of the contaminants.

Alternative 3a - Removal/Disposal (addresses human health risk)

This would adequately meet the protection requirements for human health because the BAP contaminated material would be removed from the site and deposited at an approved RCRA landfill. No pathways for future human exposure to soil would exist. This alternative would not address contamination that exceeds ecological risk threshold values. Therefore, this alternative may not be protective of the environment.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

Because this alternative includes all areas that exceed risk threshold values (human health and ecological), it would reduce risk in all areas to levels below threshold values. The alternative would eliminate the occupational exposure to BAP, eliminate the exposure of mice in Landfill No. 4 and Landfill No. 3, and eliminate the potential for toxicity to fish.

4.3.1.2 Compliance with ARARs***Alternative 1 - No Action***

There were no chemical-specific ARARs for soil contamination identified. Therefore, the no-action alternative would comply with ARARs.

Alternative 2a - Capping (addresses human health risk)

Capping would significantly reduce and possibly eliminate risk of exposure and/or accidental intrusion by human receptors. Landfill No. 4 appears to present the potential for impact to Meandering Road Creek during remediation. Primary regulatory drivers include those that would avoid impact to sensitive environmental areas (i.e., wetlands, surface waters) and those that regulate the generation, storage, treatment, and disposal of hazardous waste.

The Clean Water Act addresses issues regarding wetlands, floodplains, storm water run-off, and surface-water contamination. The Federal regulations applicable to this alternative are found in 40 CFR 129, as implemented by the TAC, Title 31, Chapter 314 (toxic pollutant effluent standards), Chapter 307 (surface water quality standards), and Chapter 311 (watershed protection). Other federal regulations include 40 CFR 125 (applicable specifically to storm water run-off during remediation), and 33 CFR 322 and 323 which deal with activities within navigable waters of the United States. The Texas Water Code, Title 2, Chapter 26, Subchapters G and I specifically address discharges of hazardous substances of pollutants into any waters of the state of Texas.

Assuming containment would not require the disturbance or relocation (thereby invoking generator requirements under RCRA) then storage, treatment, and/or disposal requirements would not be

applicable. The regulations applicable to hazardous waste are found in Appendix A. Although permits would not be required, the substantive requirements of the regulations must be complied with.

Alternative 2b - Excavation/Capping (addresses all risk areas)

This alternative would significantly reduce the risks to human and ecological receptors. Completion of this alternative would invoke the same ARARs as Alternative 2a. The requirements of Section 404 of the CWA that address dredging would be of particular concern since the alternative would remove sediments from Meandering Road Creek and Lake Worth. Also, RCRA LDR would determine whether excavated soil and sediment could be placed on Landfill No. 4.

Alternative 3a - Removal/Disposal (addresses human health risk)

If soil contaminated with characteristic hazardous waste is rendered non-hazardous through treatment (i.e., solidification) and passes the TCLP test, it may not need to be disposed at a RCRA approved landfill. However, any waste that cannot be rendered non-hazardous through approved treatment technology or any listed waste would be subject to the substantive provisions of federal and state hazardous waste regulations including generator, storage, treatment, disposal, and transportation (under the Hazardous Materials Transportation Act). Also, ARARs applicable to the protection of natural resources (i.e., CWA) would be implemented during remediation under this alternative.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

This alternative would involve the same ARARs as Alternative 3a. The requirements of Section 404 of the CWA that address dredging would be of particular concern since the alternative would remove sediments from Meandering Road Creek and Lake Worth.

4.3.1.3 Long-Term Effectiveness and Permanence

Alternative 1 - No Action

No changes in baseline health risk or ecological risk would be expected. The potential to create or add to groundwater contamination would still exist, although this was not found to cause risk in the BRA.

Alternative 2a - Capping (addresses human health risk)

The long-term residual risks under this alternative would be reduced from the baseline for human receptors since the BAP would be contained, thereby, breaking the exposure pathway. However, the source of the risk, BAP, would remain in place. Long-term maintenance of the cap and side slopes of Landfill No. 4 would be required to assure continuation of the initial level of protectiveness. If the cap is not maintained, the resulting increase in risk could reach baseline conditions (ILCR of 1.6×10^{-6}). The degree of maintenance required to maintain the cap is considered minimal and would, therefore, not be difficult. Since this alternative does not include areas with ecological risk, there would be no change in the long-term effectiveness over the baseline conditions for these areas.

Alternative 2b - Excavation/Capping (addresses all risk areas)

The long-term residual risks under this alternative would be reduced from the baseline for human and ecological receptors since the contaminants would be removed from areas where they caused risk and would be contained. However, the source of the risk for human receptors and mice would remain in place. Long-term maintenance of the cap and side slopes of Landfill No. 4 would be required to assure continuation of the initial level of protectiveness. If the cap is not maintained, the resulting increase in risk could reach baseline conditions (ILCR of 1.6×10^{-6}) for human receptors. The degree of maintenance required to maintain the cap is considered minimal and would, therefore, not be difficult.

No maintenance would be required at areas where the contaminants were excavated and placed in Landfill No. 4. The soil areas would be backfilled with clean fill.

Alternative 3a - Removal/Disposal (addresses human health risk)

Excavation of contaminated soils with subsequent transportation and disposal at a RCRA disposal facility should eliminate the residual risks for human receptors. This action would result in an incremental risk increase at the final disposal site but would represent a permanent solution to the problem at the Plant 4 site for human receptors. However, a long-term liability at the ultimate disposal facility would exist. Since this alternative does not include areas with ecological risk, there would be no change in the long-term effectiveness over the baseline conditions for these areas.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

Excavation of all contaminated soils and sediments with subsequent transportation and disposal to a RCRA disposal facility should eliminate the residual risks for human and ecological receptors. This action would result in an incremental risk increase at the final disposal site but would represent a permanent solution to the problem at the Plant 4 site. However, a long-term liability at the ultimate disposal facility would exist.

4.3.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment***Alternative 1 - No Action***

The no-action alternative would not achieve any reductions in toxicity, mobility, or volume, through treatment but still results in human health risk within acceptable limits.

Alternative 2a - Capping (addresses human health risk)

Alternative 2a would reduce the mobility of the contaminated soils that cause risk to human receptors. However, capping would not result in any reductions in contaminant toxicity or volume. There would be no change in the toxicity, mobility, or volume of soils and sediments that exceeded ecological risk threshold values.

Alternative 2b - Excavation/Capping (addresses all risk areas)

Alternative 2b would reduce the mobility of the contaminated soil and sediment that cause risk to human and ecological receptors. This alternative would not result in any reductions in contaminant toxicity or volume.

Alternative 3a - Removal/Disposal (addresses human health risk)

This alternative would reduce the mobility of BAP as a result of placing the BAP contaminated soil in a RCRA disposal cell. However, no reduction in contaminant volume or toxicity of the material would be achieved. Also, there would be no reduction in toxicity, mobility, or volume of contaminants that exceeded ecological risk threshold values.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

Removal and disposal should reduce contaminant mobility of all contaminants that exceed risk threshold values as a result of placing the contaminated materials in a RCRA disposal cell. However, no reduction in contaminant volume or toxicity would be achieved.

4.3.1.5 Short-Term Effectiveness***Alternative 1 - No Action***

The no-action alternative would not present any short-term risks to the community or workers. There would be no environmental impacts, such as construction impacts, and there are no time considerations with respect to achieving remedial response objectives.

Alternative 2a - Capping (addresses human health risk)

Construction of a cap at the Landfill No. 4 site would not be expected to present community risks other than those ordinarily associated with construction. Appropriate work zones would be established to preclude inadvertent trespassing in a construction area.

Risks to workers during cap construction would not be expected to exceed the usual risks associated with a filling-, grading-, and paving-type operation. Some excavation may also be required, especially for borrow materials. All work would be managed in accordance with the OSHA regulations applicable to the site.

There is a potential wetlands impact from construction near Meandering Road Creek. Mitigative and preventative measures would probably be required. However, impacts to Meandering Road Creek should be minimal, if any.

The length of time to complete cap construction should be less than one year, a relatively short time period for a remedial action. Since the areas of contamination that exceed ecological risk are not being addressed in this alternative, there are no time considerations with respect to achieving remedial response objectives.

Alternative 2b - Excavation/Capping (addresses all risk areas)

The same short-term effectiveness considerations that apply to Alternative 2a apply to this alternative except those that involve the areas of contamination that exceed ecological risk. Excavation of these areas is not anticipated to present risks to the community or workers above those ordinarily associated with a construction activity.

Significant short-term risks associated with this alternative are the damage that would result to Meandering Road Creek and Lake Worth from the excavation and dredging activities. Mitigative measures for Meandering Road Creek and Lake Worth would be required but would be of limited value.

This alternative would extend the time for completion of the cap by approximately one year. Soils at Landfill No. 3 and sediments in Meandering Road Creek and Lake Worth would have to be excavated and placed on Landfill No. 4 before the cap could be placed but the project should still be able to be completed within one year.

Alternative 3a - Removal/Disposal (addresses human health risk)

Removal and disposal of contaminated soils that exceeded human risk threshold values would require excavation, possible soil treatment to satisfy LDRs, storage, transportation to a RCRA landfill in compliance with the Superfund Off-Site Policy, and disposal at the landfill. Community risks primarily would be from fugitive dust emissions during excavation and loading and transporting of contaminated materials, which has a finite risk of an accident. Risks to workers would be the same as the community risks, along with the normal dangers associated with work on a construction site. The project life for this alternative is estimated at one year.

There is a potential wetlands impact from construction near Meandering Road Creek. Mitigative and preventative measures would probably be required. However, impacts to Meandering Road Creek should be minimal, if any.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

The same short-term effectiveness considerations that apply to Alternative 3a apply to this alternative except those that involve the areas of contamination that exceed ecological risk. The additional areas of excavation should not cause any additional risks to the community or the environment.

Significant short-term risks associated with this alternative are the damage that would result to Meandering Road Creek and Lake Worth from the excavation and dredging activities. Mitigative measures for Meandering Road Creek and Lake Worth would be required but would be of limited value.

This alternative could be done in one year if excavation activities at Landfill No. 3 and Meandering Road Creek was done concurrently with excavation at Landfill No. 4.

4.3.1.6 Implementability

This evaluation includes the technical and administrative feasibility of implementing the alternative and its availability in terms of equipment, materials, and services. The reliability, ease of operation, system falsifies, and administrative affairs are concerns to be addressed.

Alternative 1 - No Action

Technical Feasibility: There are no technical considerations with the no-action alternative.

Administrative Feasibility: Adoption of the no-action alternative may require gaining acceptance from the regulatory agencies and the local community of the concept that a low level of health risk from the soils may remain indefinitely.

Availability of Services and Materials: This is not an issue with the no-action alternative.

Alternative 2a - Capping (addresses human health risk)

Technical Feasibility: Capping is a well understood technique that would not be expected to present significant technical difficulties.

Administrative Feasibility: Capping should not present excessive administrative challenges. However, since the Landfill No. 4 area is adjacent to Meandering Road Creek, considerations related to wetlands regulations may be required.

Availability of Services and Materials: The construction services necessary for capping should be available locally and would be easy to procure.

Alternative 2b - Excavation/Capping (addresses all risk areas)

Technical Feasibility: Capping is a well understood technique that would not be expected to present significant technical difficulties. Excavation of soil at Landfill No. 3 and sediments in Meandering Road Creek may require hand excavation because machinery could have difficulty reaching the area. Removal of sediments from Lake Worth would probably require dredging which is a proven technology that does not create any technical problems.

Administrative Feasibility: Capping should not present excessive administrative challenges. However, since the Landfill No. 4 area is adjacent to Meandering Road Creek, considerations related to wetlands regulations may be required. Removal of sediments in Meandering Road Creek and Lake Worth may require that the conditions of a Section 404 permit be met.

Availability of Services and Materials: The construction services necessary for capping, excavation or soil and sediments, and dredging of sediments should be available locally and would be easy to procure.

Alternative 3a - Removal/Disposal (addresses human health risk)

Technical Feasibility: Excavation can be accomplished with conventional equipment although precautions against fugitive dust and personal protective equipment (PPE) may be required. The TCLP may be required to determine if the soil can be landfilled directly or if treatment prior to landfilling would be necessary to satisfy the LDRs. If treatment is necessary, it can either be performed at the Plant 4 site or at the RCRA landfill in compliance with the Superfund Off-Site Policy, if that service is provided there. The contaminated material would require transportation to the landfill, which should not present technical problems.

Administrative Feasibility: Transportation to an out-of-state disposal facility would have to be arranged. This requires compliance with the United States Department of Transportation (DOT) regulations for large hazardous waste shipments, if the material is a hazardous waste. Coordination with EPA with respect to satisfying LDRs would be required. Additionally, there may be state regulations regarding transportation and disposal of hazardous wastes which would have to be determined.

Availability of Services and Materials: The number of RCRA-permitted disposal facilities in the United States is limited, although available. Hazardous waste transporters are readily available, although planning and scheduling for their assistance would be necessary. Excavation equipment and operators should be available locally, although site specific OSHA training may be required.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

Technical Feasibility: Excavation can be accomplished with conventional equipment although precautions against fugitive dust and PPE may be required. The TCLP may be required to determine if the soil can be landfilled directly or if treatment prior to landfilling would be necessary to satisfy the LDRs. If treatment is necessary, it can either be performed at the Plant 4 site or at the RCRA landfill in compliance with the Superfund Off-Site Policy, if that service is provided there. Excavation of soil at Landfill No. 3 and sediments in Meandering Road Creek may require hand excavation because machinery could have difficulty reaching the area. Removal of sediments from Lake Worth would probably require dredging which is a proven technology that does not create any special technical problems. The excavated material would require transportation to the landfill, which should not present technical problems.

Administrative Feasibility: Transportation to an out-of-state disposal facility would have to be arranged. This requires compliance with the DOT regulations for large hazardous waste shipments. Coordination with EPA with respect to satisfying LDRs would be required. Additionally, there may be state regulations regarding transportation and disposal of hazardous wastes which would have to be researched and complied with.

Availability of Services and Materials: The number of RCRA-permitted disposal facilities in the United States is limited, although available. Hazardous waste transporters are readily available, although planning and scheduling for their assistance would be necessary. Excavation and dredging equipment/operators should be available locally, although site specific OSHA training may be required.

4.3.1.7 Cost

Alternative 1 - No Action

This alternative would have no capital cost because it proposes that no activity to achieve the RAOs. The only cost included in this alternative is monitoring.

Total Present Worth of Alternative 1 **\$73,000**

Assumptions associated with the cost estimate are:

1. Monitoring will be required for over 100 years but 50 years was the time period used to discount monitoring costs for the present worth calculation. Discounting costs for a period longer than 50 years provides an insignificant increase in the present worth. Annual cost of monitoring is \$4,000 based on two samples per year, one from Meandering Road Creek and one from Lake Worth. Cost per sample = \$2,000 (includes VOCs, SVOCs, and metals).
2. Present worth calculation based on monitoring for 50 years, discount rate of 5%.

$$\begin{aligned}\text{Present worth} &= \text{annual monitoring costs} * (P/A, 50 \text{ years}, 5\%) \\ &= \$4,000 * (18.256) \\ &= \$73,000\end{aligned}$$

Alternative 2a - Capping (addresses human health risk)

The costs associated with this alternative are given below. A breakdown of capital costs can be found in Appendix B.

Capital Cost	\$266,000
Present Worth of O&M Costs	\$91,000
Present Worth of Monitoring	\$73,000
Total Present Worth of Alternative 2a	\$430,000

Assumptions associated with the cost estimate are:

1. Landfill No. 4 will be capped.
2. The surface area requiring capping is 3.3 acres (16,000 yd²).
3. The area to be capped is assumed to be approximately close to finish grade and shall require a small amount of final grading.
4. The cap shall be asphalt, 4 inches thick, with a 6-inch compacted gravel base (2,670 yd³ of gravel, 1,780 yd³ of asphalt).
5. The area shall be fenced with 6-foot high chain link with three-strand barbed wire on top of the chain link. Two gates and signs are also included in the estimate (1,700 feet of fencing).
6. No sampling or testing has been included in this estimate.

7. Annual maintenance is estimated at \$1,000.
8. Monitoring will be required for over 100 years but 50 years was the time period used to discount monitoring costs for the present worth calculation. Discounting costs for a period longer than 50 years provides an insignificant increase in the present worth. Annual cost of monitoring is \$4,000 based on two samples per year, one from Meandering Road Creek and one from Lake Worth. Cost per sample = \$2,000 (includes VOCs, SVOCs, and metals).
9. Present worth calculation based on O&M costs for 50 years, discount rate of 5%.
O&M costs = \$1,000/year maintenance + \$4,000 for monitoring = \$5,000/year

$$\begin{aligned}
 \text{Present worth of O\&M} &= \text{annual O\&M costs} * (P/A, 50 \text{ years}, 5\%) \\
 &= \$5,000 * (18.256) \\
 &= \$91,300
 \end{aligned}$$

10. Present worth calculation based on monitoring for 50 years, discount rate of 5%.

$$\begin{aligned}
 \text{Present worth of monitoring} &= \text{annual monitoring costs} * (P/A, 50 \text{ years}, 5\%) \\
 &= \$4,000 * (18.256) \\
 &= \$73,000
 \end{aligned}$$

Alternative 2b - Excavation/Capping (addresses all risk areas)

The costs associated with this alternative are given below. A breakdown of capital costs can be found in Appendix B.

Capital Cost	\$308,000
Present Worth of O&M Costs	\$91,000
Present Worth of Monitoring Costs	\$73,000
Total Present Worth of Alternative 2b	\$472,000

Assumptions associated with the cost estimate are:

1. The surface area to be capped at Landfill No. 4 is 3.3 acres (16,000 yd²).
2. The area to be capped is assumed to be approximately close to finish grade and shall require a small amount of final grading.
3. The cap shall be asphalt, 4 inches thick, with a 6-inch compacted gravel base (2,670 yd³ of gravel, 1,780 yd³ of asphalt).
4. The area shall be fenced with 6-foot high chain link with three-strand barbed wire on top of the chain link. Two gates and signs are also included in the estimate (1,700 feet of fencing).
5. No sampling or testing has been included in this estimate.
6. Annual maintenance is estimated at \$1,000.

7. The assumed volume of soil at Landfill No. 4 that exceeds ecological risk threshold values is 555 yd³. Soil with metals contamination that exceeds ecological risk is assumed to be mixed with soil contaminated with BAP and would be removed as part of the excavation for BAP contaminated soil.
8. The assumed volume of soil at Landfill No. 3 that exceeds ecological risk threshold values is 185 yd³. All of this soil would be excavated and placed at Landfill No. 4. Because the soil is on a steep slope, half the soil volume (92 yd³) would be hand excavated.
9. Before any sediment from Meandering Road Creek or Lake Worth is removed, site-specific toxicity testing will be done on the aquatic organisms (tests on an amphipod are assumed) to determine if silver concentrations actually cause risk. The cost estimate for toxicity testing is based on sampling at 5 locations with 2 samples per location (\$900/sample) plus travel (\$2,560), shipping (\$150), and equipment (\$200) is \$11,910.
10. The assumed volume of sediment in Meandering Road Creek and Lake Worth that exceeds ecological risk threshold values is 277 yd³. The assumption is made that the site-specific toxicity testing for aquatic organisms will show that all this sediment causes risk and needs to be excavated or dredged.
11. All soils and sediments would have TCLP tests for metals done before placement on Landfill No. 4. A total of 2 tests for soils excavation from Landfill No. 3, 2 tests for sediments from Meandering Road Creek, and 2 tests for sediments from Lake Worth. Total cost is \$3,000 (\$500/sample times 6 samples).
12. Monitoring will be required for over 100 years but 50 years was the time period used to discount monitoring costs for the present worth calculation. Discounting costs for a period longer than 50 years provides an insignificant increase in the present worth. Annual cost of monitoring is \$4,000 based on two samples per year, one from Meandering Road Creek and one from Lake Worth. Cost per sample = \$2,000 (includes VOCs, SVOCs, and metals).
13. Present worth calculation based on O&M costs for 50 years, discount rate of 5%.

$$\begin{aligned}
 \text{Present worth of O\&M} &= \text{annual O\&M costs} * (P/A, 50 \text{ years}, 5\%) \\
 &= \$5,000 * (18.256) \\
 &= \$91,300
 \end{aligned}$$

14. Present worth calculation based on monitoring for 50 years, discount rate of 5%.

$$\begin{aligned}
 \text{Present worth of monitoring} &= \text{annual monitoring costs} * (P/A, 50 \text{ years}, 5\%) \\
 &= \$4,000 * (18.256) \\
 &= \$73,000
 \end{aligned}$$

Alternative 3a - Removal/Disposal (addresses human health risk)

The costs associated with this alternative are given below. All capital costs are assumed to happen within one year. There are no O&M costs for this alternative. A breakdown of capital costs can be found in Appendix B.

Capital Cost	\$19,151,000
Total Present Worth of Alternative 3a	\$19,151,000

Assumptions associated with the cost estimate are:

1. The total volume of BAP contaminated soil is 32,000 yd³.
2. The disposal site is in Alabama, 700 miles distant.
3. All excess uncontaminated excavation shall be disposed on-site.
4. No soil swell factors are included in this estimate.
5. The haul rate for excavated waste is \$0.20 per yd³ per mile.
6. Stabilization and dump charges are \$275 per yd³. All 32,000 yd³ of BAP soil would require stabilization.
7. No sampling or testing is included in this estimate.
8. No transportation permits or fees are included in this estimate.
9. Run-on and run-off diversions are 1,000 feet of ditch.
10. No monitoring will be required.
11. All costs will occur in year one.

Alternative 3b - Excavation/Disposal (addresses all risk areas)

The costs associated with this alternative are given below. All capital costs are assumed to happen within one year. There are no O&M costs for this alternative. A breakdown of capital costs can be found in Appendix B.

Capital Cost	\$19,244,000
Total Present Worth of Alternative 3b	\$19,244,000

Assumptions associated with the cost estimate are:

1. The total volume of BAP contaminated soil is 32,000 yd³.
2. The disposal site is in Alabama, 700 miles distant. The haul rate for excavated waste is \$0.20 per yd³ per mile
3. All excess uncontaminated excavation shall be disposed on-site.
4. Stabilization and dump charges are \$275 per yd³. All 32,000 yd³ of BAP soil would require stabilization. No soil swell factors are included in this estimate.
5. No sampling or testing is included in this estimate and no transportation permits or fees are included in this estimate.
6. Run-on and run-off diversions are 1,00 feet of ditch.
7. The assumed volume of soil at Landfill No. 4 that exceeds ecological risk threshold values is 555 yd³. All this soil would not require any disposal but would be removed as part of the excavation for BAP contaminated soil.
8. The assumed volume of soil at Landfill No. 3 that exceeds ecological risk threshold values is 185 yd³. All of this soil would be excavated and placed at Landfill No. 4. Because the soil is on a steep slope, half the soil volume (92 yd³) would be hand excavated.
9. Before any sediment from Meandering Road Creek or Lake Worth is removed, site-specific toxicity testing will be done on the aquatic organisms (tests on an amphipod are assumed) to determine if silver concentrations actually cause risk. The cost estimate for toxicity testing is based on sampling at 5 locations with 2 samples per location (\$900/sample) plus travel (\$2,560), shipping (\$150), and equipment (\$200) is \$11,910.
10. The assumed volume of sediment in Meandering Road Creek and Lake Worth that exceeds ecological risk threshold values is 277 yd³. The site-specific toxicity testing for aquatic organisms showed that all this sediment caused risk and needed to be excavated or dredged.
11. All soils and sediments would have TCLP tests for metals done before placement on Landfill No. 4. A total of 2 tests on soil from Landfill No. 4, 2 tests on soil from Landfill No. 3, 2 tests on sediments from Meandering Road Creek, and 2 tests on sediments from Lake Worth. Total cost = \$500 per sample times 8 samples = \$4,000
12. All soils excavated from Landfill No. 4, Landfill No.3, Meandering Road Creek, and Lake Worth could be disposed in a sanitary landfill. Costs for this material includes \$15 yd³ for loading, hauling, and unloading, and \$20 yd³ for disposal fees.
13. No monitoring will be required.
14. All costs will occur in year one.

4.3.2 Building 181

4.3.2.1 Overall Protection of Human Health and the Environment

Alternative 1 - No Action

There is no direct exposure to the TCE in the vadose zone under Building 181 so the no-action alternative would not affect present or future risk from exposure to TCE in the vadose zone. The TCE in the vadose zone does cause risk threshold values to be exceeded in the groundwater. Therefore, the no-action alternative is not protective of human health and the environment without treatment of groundwater contaminated by TCE from the vadose zone.

Alternative 2 - Soil Vapor Extraction

SVE provides both short-term and long-term protection from further groundwater contamination by reducing concentration levels of TCE in the vadose to those levels that would not cause groundwater cleanup levels to be exceeded. The SVE alternative cannot by itself eliminate risk in the groundwater and be protective of human health and the environment because additional sources contribute to groundwater contamination. However, SVE would decrease the amount of groundwater remediation required which improves the ability of any groundwater remediation alternative to meet its cleanup criteria.

4.3.2.2 Compliance with ARARs

Alternative 1 - No Action

There were no chemical-specific or action-specific ARARs for the TCE contamination in the vadose zone under Building 181. Therefore, the no-action alternative would comply with ARARs for the vadose zone. The no-action alternative would result in continued contamination of the groundwater that would cause contamination in the Paluxy aquifer above regulatory and calculated risk-based levels.

Alternative 2 - Soil Vapor Extraction

The SVE alternative would eliminate a source of contamination which has caused concentration levels of TCE to exceed regulatory levels in the Paluxy aquifer. Implementation of SVE would require emission controls to ensure compliance with air quality standards. SVE does not trigger RCRA Land Disposal Restrictions (LDRs) because it does not involve placement of waste. Because waste is removed in place through limited construction and no excavation, no impacts to wetlands, floodplains, or water quality are foreseen.

4.3.2.3 Long-Term Effectiveness and Permanence

Alternative 1 - No Action

The no-action alternative would have no effect on reducing risk so that the residual risk would be the same as the baseline risk. There would be no change in the long-term effectiveness, and permanence would not change.

Alternative 2 - Soil Vapor Extraction

SVE would remove the TCE in the vadose zone resulting in permanent removal of contaminants. Because contaminants are permanently removed, SVE is considered to be effective over the long-term. The effectiveness of SVE at removing VOCs from the vadose zone has been well demonstrated. Treatment of residuals in the vapor phase carbon adsorption canisters would be required. This is generally done through regeneration or disposal. Periodic maintenance of the system would be required to maintain effectiveness. The SVE alternative would significantly reduce risk from residual TCE in the vadose zone.

4.3.2.4 Reduction of Toxicity, Mobility, or Volume Through Treatment***Alternative 1 - No Action***

The no action alternative would not reduce the toxicity, mobility, or volume of TCE in the vadose zone over the baseline condition.

Alternative 2 - Soil Vapor Extraction

By permanently removing the TCE in the vadose zone, the SVE alternative would significantly reduce mobility and volume. Toxicity is reduced by removal of the mass of TCE in the vadose zone. Although the SVE process removes the TCE from the vadose zone, it is not destroyed but only transferred to the carbon adsorption canisters. The TCE is destroyed when the carbon adsorption canisters are regenerated.

4.3.2.5 Short-Term Effectiveness***Alternative 1 - No Action***

There are no short-term risks to the community, on-site workers, or the environment from the no-action alternative. The no-action alternative has no effect on short-term effectiveness over the baseline condition.

Alternative 2 - Soil Vapor Extraction

The SVE alternative would not present substantive risks to the community, on-site workers, or the environment. Perhaps the most significant short-term risk is the potential for dust generation during well installation. Potential air emissions are easily controlled through carbon adsorption.

A relatively short time frame would be required to remove the TCE from the vadose zone. However, the quantity of TCE in the vadose zone is not known and there is no characterization data that can be used to provide an estimate of the quantity of TCE in the vadose zone. There are estimates that 20,000 gallons of TCE have leaked from Building 181 in the past. For the purpose of estimating a time to remove the TCE, the assumption is made that 5,000 gallons still remain in the vadose zone (based on the assumption that 25 percent of the TCE would still be in the vadose zone).

The removal rate for the SVE system is estimated at approximately 1,000 gallons per year. This rate is based on the 90-day pilot tests where approximately 260 gallons were removed. Assuming 1,000 gallons

per year are removed from the vadose zone, cleanup could be reached in five years. It should be stressed that there is considerable uncertainty in estimating the time for cleanup. Performance of the SVE system is highly dependent upon the lithology of the site.

4.3.2.6 Implementability

Alternative 1 - No Action

The no-action alternative is readily implemented. There are no administrative or technical difficulties in implementing the alternative.

Alternative 2 - Soil Vapor Extraction

The SVE alternative would be relatively easy to implement. There are few administrative difficulties. The technology is readily available from many sources and has been used successfully at numerous Superfund sites to address VOC contamination. Installing and operating extraction wells requires fewer engineering controls than other technologies such as incineration or excavation. A series of soil gas sampling wells would be required to determine when clean-up levels are achieved.

4.3.2.7 Cost

Alternative 1 - No Action

There are no costs associated with the no-action alternative. Monitoring of the vadose zone was assumed not to be part of this alternative. Monitoring of the groundwater under Building 181 would be part of the selected alternative for the East Parking Lot Plume.

Alternative 2 - Soil Vapor Extraction

The costs associated with the soil vapor extraction system are given below. A breakdown of capital costs is included in Appendix B.

Capital Costs	\$259,000
Present Worth of O&M Costs	\$353,000
Total Present Worth of Alternative 2	\$612,000

Assumptions associated with the cost estimate are:

1. Cost of pilot-scale testing is not included.
2. Perched well costs are estimated at \$200/ft for a completed well with stainless steel casing and screen at 5 feet deep.
3. Upper Zone well costs are estimated at \$200/ft for a completed well with stainless steel casing and screen at 25 feet deep.
4. Activated carbon costs estimated at \$3/lb.

5. Installation fee assumed to be 5% of capital costs.
6. Engineering fees assumed to be 15% of capital costs.
7. Contingency assumed at 15% of total costs.
8. Groundwater treatment is not included in the alternative.
9. Present Worth of O&M calculations based on \$104,500/year for years 2 through 5 and a discount rate of 5 percent.

$$\begin{aligned}
 \text{Present worth of O\&M} &= \text{yearly O\&M costs} * (P/A, 4 \text{ years}, 5\%) * (P/F, 1 \text{ year}, 5\%) \\
 &= \$104,500 * (3.546) * (0.9524) \\
 &= \$353,000
 \end{aligned}$$

4.4 Comparative Analysis

The comparative analysis reviews the candidate remedial activities described in previous sections in relation to threshold criteria, primary balancing criteria, and modifying criteria as specified in the NCP. The threshold criteria include overall protection of human health and the environment and compliance with ARARs. These two criteria must be met by an alternative to be eligible for selection. Primary balancing criteria include long-term effectiveness and permanence, reduction of toxicity, mobility, or volume through treatment, short-term effectiveness, implementability, and cost. Modifying criteria include state and community acceptance. The comparative analysis is presented in the following tables.

4.4.1 Groundwater Alternatives

4.4.1.1 Paluxy Aquifer Alternatives

Table 4-1 presents a summary of the comparative analysis for the Paluxy aquifer alternatives.

Threshold Criteria

The No-Action Alternative, Alternative 1, does not meet the requirement to be protective of human health and the environment nor would it comply with ARARs. Alternatives 2 and 3, Institutional Controls and Pump and Treat, respectively, would both be protective of human health and the environment. However, Alternative 2 would comply with some ARARs but not all. In particular, it does not comply with the NCP's requirement that drinking water aquifers be returned to MCLs or non-zero MCLGs. Alternative 3 would comply with all ARARs.

Balancing Criteria

Alternative 3 provides the best long-term effectiveness and is the most permanent solution because contaminants are removed from the aquifer. Alternative 2 is effective, but is less permanent because contamination is left in the aquifer. The No-Action Alternative provides some degree of long-term effectiveness because natural attenuation of the plume would reduce the concentration of contaminants. Alternatives 1 and 2 provide no reduction in toxicity, mobility, or volume of contaminants. Only Alternative 3 reduces toxicity, mobility, or volume through treatment.

Table 4-1. Comparative Analysis of Paluxy Aquifer Alternatives

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Criteria	Alternative 1 No Action	Alternative 2 Alternate Water Supply	Alternative 3 Extraction w/ Air Stripping Treatment	Alternative 3 Extraction w/ UV Oxidation Treatment
Overall Protection of Human Health and the Environment	Contaminants unmitigated, may impact White Settlement production wells in time	Contaminants unmitigated, safe; alternative water supply provided for White Settlement	Protection of human health and environment through removing metals and dissolved organic contaminants through air stripping	Protection of human health and the environment through removing metals and destroying dissolved organic contaminants through UV/oxidation, respectively
Compliance with ARARs	Would not comply with ARARs	Complies with some but not all ARARs	Would comply with ARARs	Would comply with ARARs
Long-Term Effectiveness and Permanence	No long-term effectiveness or permanence	Permanent long-term positive health effect for White Settlement population. No effect on plumes.	Effective in removing volatiles from the ground-water - permanent solution for extracted contaminants.	Effective in destroying volatiles in the ground-water, a permanent solution
Reduction of Toxicity, Mobility, or Volume Through Treatment	Reduction in toxicity and volume over time through natural attenuation. No change to mobility. No reduction in toxicity, mobility, or volume through treatment.	Reduction in toxicity and volume over time through natural attenuation. No change to mobility. No reduction in toxicity, mobility, or volume through treatment.	Reduces mobility and volume through ground-water well pumping, reduces toxicity by destroying dissolved organic contamination through UV/oxidation.	Reduces mobility and volume through ground-water well pumping, reduces toxicity by destroying dissolved organic contamination through UV/oxidation.
Short-Term Effectiveness	No impact to the community or workers.	No expected impacts. Expected life is 1 year.	Safety requirements for system installation. No expected impacts to workers or nearby communities. Expected project life is 7 years.	Safety requirements for system installation. No expected impacts to workers or nearby communities. Expected project life is 7 years.
Implementability	Requires no action to implement. Easiest to implement.	Services, vendor, and equipment readily available. Requires coordination with the town of White Settlement.	Straight forward construction and operation. Services, vendors, and technology are readily available. Water quality parameters and updated dissolved contaminant concentrations concentrations needed.	Straight forward construction and operation. Services, vendors, and technology available. Water quality parameters and updated dissolved contaminant concentrations required. Pre-treatment of water may be required depending upon water quality. Treatability testing may be required.
Cost	\$274,000	\$937,000	\$2,541,000	\$3,101,000

Alternative 3 involves the most activities to complete providing the highest potential for risk to the community and workers. It also takes the longest time to complete, 7 years. The no action alternative provides the least risk to the community and workers and shortest time to implement. However, all alternatives are relatively easy to implement because readily available technology would be used. The No-Action Alternative is the easiest to implement followed by alternative 2. The cost of Alternative 3 is the highest, followed by Alternative 2, with the No-Action Alternative costing the least.

4.4.1.2 East Parking Lot Plume Alternatives

Table 4-2 presents a summary of alternatives for the East Parking Lot Plume. Treatment alternatives are included, where applicable.

Threshold Criteria

Alternative 3, Enhanced Source Removal, provides the best protection of human health and the environment. It has the highest potential of removing DNAPL from the groundwater. This alternative would comply with ARARs, although ARARs for injection of the surfactants are not readily identified. Alternative 2, Traditional Pumping, eventually would remove the DNAPL and, therefore, be protective of human health and the environment, but it would take over 100 years. Alternative 2, Traditional Pumping, eventually would remove the DNAPL and therefore, be protective of human health and the environment, but it would take over 100 years. Alternative 2 also would comply with ARARs. The No-Action Alternative, Alternative 1, would not be protective and would not comply with ARARs.

Balancing Criteria

Alternative 2 is effective at removing or destroying contaminants in the extracted groundwater but is not effective at removing DNAPL from the groundwater. Traditional pumping relies on dissolution of the DNAPL. Because TCE has a low solubility, the estimated time for the DNAPL to dissolve and allow cleanup levels to be reached is over 100 years. The No-Action Alternative would take longer to dissolve the DNAPL than Alternative 2. Alternative 3 could remove the DNAPL and reach cleanup levels within 15 years. Alternatives 2 and 3 both reduce toxicity, mobility, and volume treatment.

The No-Action Alternative would have the least effect on risk to workers and the community from a remedial action but would have the longest time to reach cleanup levels. Alternative 2 would have minimal risks to workers and the community but has a very long remediation time, greater than 100 years. Alternative 3 would be the most intensive remedial action and have the highest risks to workers and the community, although the risks would not be significant. However, Alternative 3 has a substantially shorter project life, 15 years. Since Alternative 3 is an innovative technology, there is considerably more uncertainty with its performance than with established technology. However, there are no established technologies for remediation of DNAPL.

The No-Action Alternative would be the easiest to implement. Alternative 2 would be the easiest alternative to implement of the treatment alternatives. Alternative 3 is an innovative technology and is therefore not proven. Implementation of Alternative 3 would be the most difficult. Excluding no action, Alternative 2 with air stripping as the treatment method is the least expensive. Alternative 3 is more expensive than Alternative 2 with air stripping but less than with the other treatment methods.

Table 4-2. Comparative Analysis of East Parking Lot Groundwater Alternatives

Criteria	Alternative 1 No Action	Alternative 2 Extraction w/ Air Stripping Treatment	Alternative 2 Extraction w/ UV Oxidation Treatment	Alternative 3 Enhanced Extraction w/ Air Stripping Treatment
Overall Protectiveness	Contaminants may impact the While Settlement production wells in time. Least protective alternative.	Treatment method is protective because dissolved contaminants are removed. Extraction method does not provide protection for a long time.	Treatment method is protective because dissolved contaminants are destroyed. Extraction method does not provide protection for a long time.	Treatment method is protective because dissolved contaminants are removed. Extraction method provides protection within a reasonable time. Most protective alternative.
Compliance with ARARs	Would not comply with ARARs	Would comply with ARARs	Would comply with ARARs	Would comply with ARARs
Long-Term Effectiveness and Permanence	Alternative does not provide long-term effectiveness and is not a permanent solution.	Effective at removing VOCs from extracted groundwater, a permanent solution. Extraction method not effective at removing DNAPL. Less effective than Alternative 3.	Effective at destroying VOCs in extracted groundwater, a permanent solution. Extraction method not effective at removing DNAPL. Less effective than Alternative 3.	Air stripping is effective in removing VOCs from extracted groundwater. Enhanced extraction would help remove DNAPL. Most effective alternative but considerable uncertainty with effectiveness because it is an innovative technology.
Reduction of Toxicity, Mobility, or Volume Through Treatment	Reduction in toxicity and volume over time, no change to mobility	Reduces mobility and volume through groundwater pumping, reduces toxicity through treatment with air stripping	Reduces mobility and volume through groundwater well pumping, reduces toxicity by destroying dissolved organic contamination through UV/oxidation.	Reduces mobility and volume by removing DNAPL source areas, reduced toxicity through treatment with air stripping.
Short-Term Effectiveness	No risks to the community or workers but natural attenuation would take the longest time.	Safety requirements for system installation. No expected impacts to workers or nearby communities. Expected project life is > 100 years.	Safety requirements for system installation. No expected impacts to workers or community. Expected project life is > 100 years.	Safety requirements for system installation. No expected impacts to workers or nearby communities. Project life is 15 years.
Implementability	No action to implement	Services, vendors, and technology are readily available. Easiest alternative to implement.	Services, vendors, and technology are readily available. Pre-treatment of water may be required. Treatability testing may be required. Easier to implement than Alternative 3.	Innovative technology, has not been proven at full-scale. Pilot testing required. Most difficult alternative to implement.
Cost	\$822,000	\$6,882,000	\$7,334,000	\$9,865,000

4.4.1.3 Treatment Alternatives

Threshold Criteria

The treatment alternatives are included with the Paluxy aquifer and East Parking Lot Plume alternatives. Presented here is a comparison of the different treatment alternatives. All treatment alternatives would comply with ARARs. There is essentially no difference in their ability to comply with ARARs.

Balancing Criteria

Chemical treatment degrades the compounds into non-toxic compounds providing the best reduction in toxicity, mobility, and volume reduction. Physical treatment provides the least reduction in toxicity, mobility, and volume because it does not destroy the contaminants but rather volatilizes them. Since the contaminant is merely changing state, it does not provide the same level of protectiveness as chemical treatment. Physical treatment is the best alternative in terms of cost.

Physical treatment is not as complex as chemical treatment and, therefore, tends to be more reliable. Because of its complexity, chemical treatment is more prone to requiring repair. Chemical treatment relies on physical processes to degrade the contaminant. Physical treatment is the easiest to implement.

4.4.2 Soil

Table 4-3 provides a summary of the comparison of alternatives for Landfill No. 4, Landfill No. 3, and Meandering Road Creek.

4.4.2.1 Landfill No. 4, Landfill No. 3, and Meandering Road Creek

Threshold Criteria

The No-Action Alternative, Alternative 1, for contaminated soils at Plant 4 provides protection to human health within the acceptable range and complies with ARARs. Compliance with ARARs would be achieved since no ARARs specific to soil contamination were identified. The BRA calculated an ILCR of 1.6×10^{-6} , which only slightly exceeds the threshold value of 1.0×10^{-6} . This risk is within the acceptable range of risk (1.0×10^{-4} to 1.0×10^{-6} ILCR). Also, the central tendency evaluation calculates the risk to be below the 1.0×10^{-6} ILCR threshold value.

Contaminants in the soil and sediment exceeded threshold values that indicate the potential for ecological harm. The no action alternative would do nothing to address the potential ecological risk. However, the potential ecological risk should be examined more closely. Ecological risk at Landfill No. 4 and Landfill No. 3 is only to mice, not to predators that feed on the mice. The potential toxicity to aquatic organisms in Meandering Road Creek is based on sediment quality criteria in a marine environment, not on site-specific conditions.

Alternative 2a, the Capping Alternative, that only considers human health risk, would reduce the human exposure to BAP to below threshold values. Compliance with ARARs should be achieved since no ARARs specific to soil contamination were discovered. This alternative does not address areas where contamination exceeds ecological risk threshold values. A risk management decision not to remediate areas that exceeded ecological risk threshold values is required for this alternative to be a viable.

Table 4-3. Comparative Analysis of Soil Alternatives for Landfill No. 4, Landfill No. 3, and Meandering Road Creek

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Criteria	Alternative 1 No Action	Alternative 2a Capping (human health)	Alternative 2b Capping (all risk areas)	Alternative 3a Removal/Disposal (human health)	Alternative 3b Removal/Disposal (all risk areas)
Overall Protection of Human Health and the Environment	Within allowable risk range for human health but may not be protective of the environment.	Reduces human health risk but does not address potential ecological risk.	Reduces human health and ecological risk. More protective than no action and alternative 2a.	Reduces human health risk but does not address potential ecological risk. More protective of human health than no action and capping.	Reduces human health and ecological risk to below threshold values. Most protective of all alternatives.
Compliance with ARARs	Alternative would comply with ARARs.	Alternative would comply with ARARs.	Alternative would comply with ARARs.	Alternative would comply with ARARs but requires compliance with the most ARARs than capping or no action.	Alternative would comply with ARARs but requires compliance with the most ARARs.
Long-Term Effectiveness and Permanence	No changes in BRA condition expected. Least effective of all alternatives.	Effective at reducing health risks to below threshold values but requires periodic maintenance. Not effective at reducing the potential ecological risk. More effective than no action.	Effective at reducing health and ecological risks to below threshold values but requires periodic maintenance. More effective than no action and alternative 2a.	Effective at reducing human health risks on-site, but long-term liabilities exist at final disposal site. More effective at reducing human health risk than no action and capping.	Effective at reducing human health and ecological risks on-site, but long-term liabilities exist at final disposal site. Most effective alternative.
Reduction of Toxicity, Mobility, or Volume Through Treatment	No reduction in toxicity, mobility, or volume.	Mobility of BAP is reduced but no change in toxicity or volume. Better than no action at reducing mobility. Does not reduce mobility, toxicity, or volume through treatment.	Mobility of all contaminants is reduced but no change in toxicity or volume. Does not reduce mobility, toxicity, or volume through treatment. Better than no action and alternative 2a at reducing mobility.	Mobility of BAP is reduced but no change in toxicity and volume because BAP still exists at disposal site. No effect on ecological contaminants. Better than no action and capping at reducing mobility.	Mobility of all contaminants are reduced but contaminants would still exist at disposal site. Best alternative at reducing mobility.
Short-Term Effectiveness	No short-term risks. Best alternative for short-term risks.	Small risk expected during construction activities. Small risk of wetlands impact.	Small risk expected during construction activities. Significant short-term risk to Meandering Road Creek and Lake Worth from excavation and dredging.	Small risk expected during construction activities. Small risk of wetlands impact. Transportation related risks. More short-term risks than no action and capping.	Small risk during construction. Significant risk to Meandering Road Creek and Lake Worth from excavation/dredging. Transportation related risk. Worst alternative for short-term risk.
Implementability	Easiest to implement but may be difficult to obtain acceptance of no-action risk.	Easiest to implement, except for no action, but may be difficult to obtain acceptance of no action for ecological risk.	Easy to implement, but slightly more difficult than no action and alternative 2a.	Transportation issues to be resolved but services are available. More difficult to implement than no action and capping.	Transportation issues to be resolved but services are available. Most difficult alternative to implement.
Cost	\$73,000	\$430,000	\$472,000	\$19,151,000	\$19,244,000

Alternative 2b, the Capping Alternative that addresses all risk areas, would effectively reduce both human health and ecological risk to below threshold values. Compliance with ARARs should be achieved since no ARARs specific to soil contamination were discovered. Because this capping alternative addresses all risk areas, it meets the threshold criteria better than the capping alternative that only addresses human health risk areas.

Alternative 3a, the Removal/Disposal Alternative that only considers human health risk areas, removes BAP contamination from the Plant 4 site, thereby affording the largest reduction of human health risk. The process is relatively easy to implement and should be successful, from a construction standpoint. The drawbacks include very high cost, the ongoing liability considerations that would exist at the ultimate disposal site should the disposal site ever be subject to a CERCLA action in the future, and the potential complexity of ARAR considerations since the excavated wastes may be subject to RCRA.

Alternative 3b, the Removal/Disposal Alternative that addresses all risk areas, would effectively reduce both human health and ecological risks to below threshold values. Alternative 3b has the same considerations for protectiveness and ARAR compliance that apply to Alternative 3a except that Alternative 3b would be protective of all areas. ARAR compliance for Alternative 3b would be the most complex of any alternative but it also would be the most protective of any alternative.

Balancing Criteria

The No-Action Alternative is the best alternative in terms of cost, short-term effectiveness, and implementability. It is less effective over the long-term than the other alternatives but it still results in human health risk within the acceptable range. It is not effective at reducing the potential ecological risk calculated in the BRA and it has the least reduction in toxicity, mobility, or volume of all the alternatives.

Excluding the No-Action Alternative, Alternative 2a is the best for short-term effectiveness and Alternative 3b is the worst. Alternative 2b also has significant short-term risk because of excavation and dredging activities required to remove the soils and sediments from wetlands areas. Alternatives 3a and 3b are the hardest to implement but are still relatively easy to implement and should be successful from a construction standpoint.

Long-term effectiveness is the highest for Alternatives 3a and 3b but the Air Force would have ongoing liability considerations at the ultimate disposal site. Alternatives 2a and 2b are relatively easy to implement, although harder to implement than the No-Action Alternative but easier than the removal/disposal alternatives. Alternatives 2a and 2b do not reduce toxicity or volume and are no different than the No-Action Alternative in this regard. They do decrease mobility more than the No-Action Alternative but less than Alternatives 3a and 3b. However, Alternatives 2a and 2b do not meet the preference of the NCP for reduction of mobility, toxicity, or volume through treatment.

Costs are significantly less for Alternatives 2a and 2b than for Alternatives 3a and 3b. Alternative 3b has the highest cost and Alternative 2a has the lowest cost, excluding the No-Action Alternative. The high costs of Alternatives 3a and 3b are perhaps the biggest disadvantage of these alternatives.

Table 4-4 compares the alternatives for Building 181 for each of the seven evaluation criteria.

Threshold Criteria

The No-Action Alternative, Alternative 1, is protective of human health and the environment only for soil in the vadose zone since there is no exposure to the soil. It is not protective of the groundwater. SVE, Alternative 2, would provide better protection of human health and the environment since it would stop contamination of the groundwater. Both alternatives would comply with ARARs. Since SVE would extract TCE from the vadose zone it is subject to standards concerning air emissions and final disposal of the TCE.

Balancing Criteria

Compared to the SVE Alternative, the No-Action Alternative has lower costs, less short-term risk, and is easier to implement. However, the short-term risks of the SVE Alternative are minimal and the advantage of the No-Action Alternative over the SVE Alternative for this criteria are minimal. Also, the SVE Alternative would be relatively easy to implement so the No-Action Alternative advantages for this criteria are minimal. The No-Action Alternative does not have any costs but would result in higher groundwater treatment costs. The SVE Alternative is much better than No-Action Alternative for long-term effectiveness and permanently removes contaminants from the vadose zone. Also, the SVE Alternative provides reduction in toxicity, mobility, and volume through treatment where the No-Action Alternative does not provide any reduction.

Table 4-4. Comparative Analysis of Soil Alternatives for Building 181

Criteria	Alternative 1 No Action	Alternative 2 Soil Vapor Extraction
Overall Protection of Human Health and the Environment	Protective of human health and the environment only for exposure to soil in the vadose zone, not protective of groundwater.	Protective of human health and the environment for both the soil in the vadose zone and the groundwater.
Compliance with ARARs	Complies with ARARs related to TCE in the soil because there are no ARARs requiring action. Does not comply with groundwater ARARs.	Release of TCE to the atmosphere is the main ARAR. Alternative would comply with ARARs.
Long-Term Effectiveness and Permanence	Allows continued mitigation of TCE to the groundwater. No change over baseline condition.	Residual risks are significantly reduced because the TCE is permanently removed. SVE has been demonstrated at many sites to be effective, where site conditions warrant its use. Pilot tests have shown SVE to be effective at this site.
Reduction of Toxicity, Mobility, or Volume through Treatment	No reductions in toxicity, mobility, or volume over baseline condition.	Reduces toxicity, mobility, and volume through treatment. TCE removed from the vadose zone is not destroyed until regeneration of the carbon adsorption canisters.
Short-Term Effectiveness	No short-term risks to the community, workers, or the environment.	Small risk potential to workers in the plant from TCE vapor but controls for the TCE vapor are effective. Estimated cleanup time is 5 years.
Implementability	Easy to implement. There are no administrative or technical difficulties.	Relatively easy to implement. Technology is available from many sources and it uses material that is readily available.
Cost	No cost	\$612,000

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